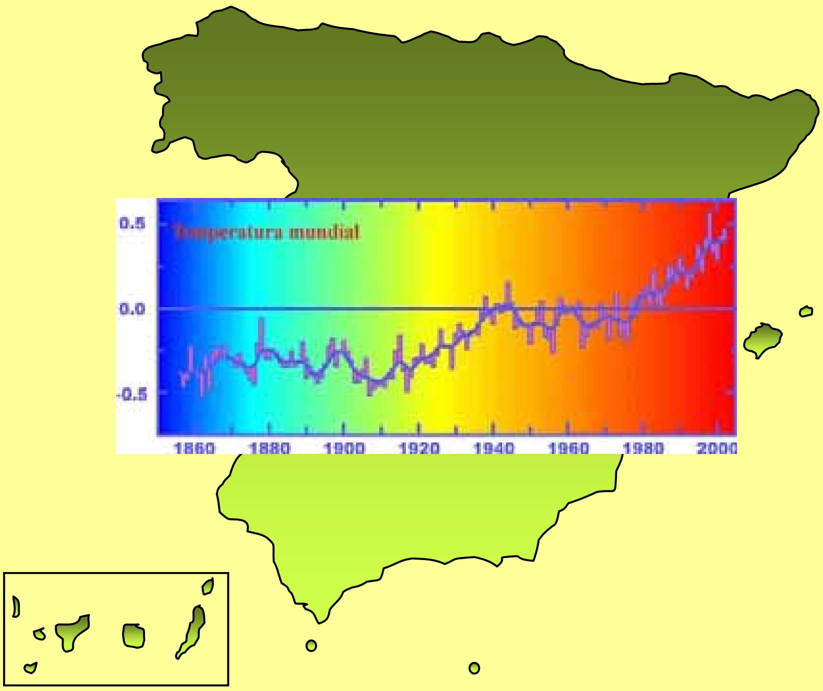
A Preliminary General Assessment of the Impacts in Spain Due to the Effects of Climate Change



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A Preliminary Assessment of the Impacts in Spain due to the Effects of Climate Change

ECCE PROJECT - FINAL REPORT

Carried out under the Agreement between the Ministry of the Environment and the University of Castilla La Mancha for conducting "A Preliminary Assessment of the Impacts in Spain due to the Effects of Climate Change"

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MINISTERIO DE MEDIO AMBIENTE

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PRESENTATION

This preliminary assessment on the possible impacts of climate change in the different ecosystems and socio-economic sectors in Spain constitutes one more step in the efforts by the Ministry of the Environment to make advances in the fight against climate change.

We are all aware that the changes occurring in the climate have already affected many physical and biological systems and that the projected risks of climate change are very great, and that adaptation to future climatic conditions is inevitable. The short- and long-term adaptation needs ought to be framed within a broader context of sustainable development and be integrated into sectorial policies. Prompt planning of this adaptation could lessen vulnerability to impacts and reduce costs.

The actions for adaptation must be considered from two points of view: on one hand, the application of measures aimed at minimising effects in the socio-economic sectors and ecosystems most susceptible to climate change and, on the other, risk prevention related to extreme climatic phenomena and the effects thereof. However, it must not be forgotten that best way to combat climate change is through mitigation, which involves reducing emissions of the gases that cause it.

Spain's geographic location and socio-economic characteristics make us very vulnerable to climate change, the effects of which we have recently suffered. Among other aspects, the impacts of climate change can have particularly serious consequences in relation to reduced hydric resources, coastal retreat, loss of biodiversity and natural ecosystems, increased soil erosion processes and loss of human lives and property resulting from the intensification of the adverse events associated with extreme climatic phenomena, such as floods, forest fires and heat waves.

The results of this preliminary assessment, drawn up by fifty authors, in collaboration with other experts belonging to a wide range of Spanish universities and research centres, undoubtedly constitute a basic element and the key, on one hand, to learning more about the vulnerability of our ecosystems and sectors to the impacts of climate change and, on the other, to developing and establishing adaptation policies enabling the Public Administrations and the private sector to adopt measures.

From my post of responsibility, as Minister of the Environment, I will do all I can to promote – in co-ordination and collaboration with the Regional Autonomies and with the support of our scientific and academic community – the policies required of us by the challenge posed by climate change.

Cristina NARBONA RUIZ
Minister of the Environment

PROLOGUE

The report Preliminary Assessment of the Impacts of Climate Change in Spain results from the efforts of a large group of experts, aimed at determining the changes that will take place throughout the XXI century in Spain's climate as a consequence of the global warming of the planet and how these changes can affect the natural environment, the resources thereof, some of the main production sectors and human health in our country. The analysis conducted followed the procedures established by the IPCC or, in the case of Europe, by the ACACIA project. To this end, we brought together a group of experts from different fields of knowledge, different institutions and different parts of Spain. Apart from climate, we selected fifteen thematic areas relating to impacts. To each theme, we assigned three experts, who were charged with exhaustively reviewing the existing knowledge of the interactions between climate and the object of study, and, based upon this and upon future climate projections, these experts were to predict the consequences of climate change as the century elapses. In order to ensure as broad and contrasted a view as possible of each theme, the authors of each chapter were requested to glean the opinion of other experts, both in the drafting and review processes, the help of experts from abroad being drawn upon in the latter case.

The chapter on climate deals with recent change tendencies and future climate. The remaining chapters have been arranged into ten sections:1) introduction, 2) relationship with present climate, 3) foreseeable impacts of climate change, 4) most vulnerable areas, 5) main adaptation options in relation to climate change, 6) repercussions of each system or sector for the other ones, 7) existing knowledge gaps, 8) possibilities of detecting change, 9) implications for policies, 10) main research needs.

The future climatic or socio-economic reference framework was drawn up by the IPCC. In some cases, projections were used which were based on regional climate models. Given the fact that there have been few specific studies of the impacts of climate change in Spain, in most cases, the conclusions expressed reflect the opinion of the experts. Based upon knowledge of the relationships between climate and the processes we are dealing with, and in view of the foreseeable changes, this is the course we expect things to take throughout the century. The existing lack of knowledge hinders more detailed determination of the impacts. In any case, the impacts to be expected are so many, and of such a varying nature, that in no case must the lack of detailed knowledge serve as an excuse not to take action, right here and now. Extreme events, however, such as the 2003 heat wave, show how the manifestations of climate change can surprise us. Time has simply run out with regard to taking measures. The report provides us with sufficient elements to make adaptations and to mitigate the consequences of the climate change in which we clearly appear to be immersed.

The report was written in Spanish and translated into English. I wish to acknowledge the collaboration of the authors, contributing authors, reviewers and technical backup staff, and the help provided by the Spanish Bureau of Climatic Change in the drafting of the ECCE project, which resulted in this report.

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A Preliminary Assessment of the Impacts in Spain due to the Effects of Climate Change

Contents

Summary and main conclusions and recommendations

The Spanish climate

Spain's climate is extremely varied as a result of its complex topography and geographic location. Interannual climatic variability is high and is conditioned to a great extent, specifically with regard to rainfall, by atmospheric circulation patterns in the Northern hemisphere, in particular by the North Atlantic oscillation (NAO).

During the XX century, temperatures in Spain showed a general increase, with a magnitude greater than the global average. This is more accentuated in winter. Rainfall during this period showed a downward trend, especially in the South and in the Canary Isles, although the high variability involved prevents a more precise judgement. This tendency partly corresponds to an increase in the NAO index.

The tendencies of future climate depend upon the socioeconomic scenarios used and vary according to the general climate models employed. The temperature increase projected for the Iberian peninsula according to whether more or less favourable scenarios are used (less or more emissions, respectively) is uniform throughout the XXI century, with a mean tendency of 0.4 ºC/decade in winter and 0.7 ºC/decade in summer for the less favourable scenario (A2 according to the IPCC), and of 0.4 ºC and 0.6 ºC/decade, respectively, for the more favourable scenario (B2 of the IPCC).

With regard to rainfall, the change tendencies throughout the century are not generally uniform, with noteworthy discrepancies between the global models, which makes the result less reliable. They all, however, coincide in a significant reduction in total annual rainfall, somewhat greater in scenario A2 than in B2. These reductions are maximum in spring and somewhat lesser in summer.

The application of regional models allows the detail of climatic projections to be enlarged. The results of one of these models (*PROMES*) for the last third of the century provides these data: temperatures will increase by between 5 and 7ºC in summer and by 3 to 4ºC in winter, and will be somewhat lower on the coasts than inland, and also lesser (aprpox. 1º) for scenario B2 than for A2.

The changes in rainfall are more heterogeneous, with an accentuation in the Northwest-Southeast gradient in winter and autumn, with slight increases in one and decreases in the other. In spring and, above all, in summer, the decrease in rainfall is a generalised one. These variations are more accused in scenario A2 than in B2.

The frequency and range of monthly temperature anomalies increases in all seasons and in both scenarios, although there is great geographic variability. The changes in monthly rainfall anomalies are not conclusive.

The frequency of days with high temperatures increases in spring and autumn, although it is not conclusive on the islands. The days with minimum temperatures tend to decrease.

Considering the set of results for climate change projected throughout the XXI century for Spain by the different climate models considered, we can arrange their degree of reliability in a descending direction in the following way: 1: progressive tendency to increase of mean temperatures throughout the century. 2: Tendency towards more notable warming in a scenario of higher emissions. 3: The increases in mean temperature are significantly greater in the summer months than in winter ones. 4: Warming in summer is greater in the inland areas than on the coast or on the islands. 5: Generalised tendency towards less annual accumulated rainfall. 6: Greater range and frequency of monthly temperature anomalies. 7: greater frequency of days with extreme maximum temperatures on the Peninsula, especially in summer. 8: For the last third of the century, the greater reduction of rainfall on the Peninsula is projected in the months of spring. 9: Increased rainfall in the West of the Peninsula in winter and in the Northeast in autumn. 10: The changes in rainfall tend to be more significant in the scenario of higher emissions.

Main impacts of climate change in Spain

Terrestrial ecosystems

Climate change will affect the structure and functioning of terrestrial ecosystems, will alter the phenology and interactions among species, will favour the spread of invasive species and pests and will increase the impact of both natural and anthropic disturbances. The areas and ecosystems most vulnerable to climate change are islands and isolated ecosystems, such as edaphic islands and high-mountain systems, and ecotones, or areas of transition between systems.

Inland aquatic ecosystems

With a high degree of certainty, climate change can be expected to make many of Spanish continental aquatic ecosystems (SCAE) change from permanent to seasonal; some will disappear. The biodiversity of many of them will be reduced and their biogeochemcial cycles will be altered. The magnitude of these changes cannot yet be established. The ecosystems most affected will be: endorheic environments, lakes, lagoons, rivers and high-mountain streams (1600-2500 metres), coastal wetlands and environments depending upon subterranean waters.

Marine ecosystems and the fisheries sector

The effects of climate change will differ for upwelling ecosystems or those comprising stratified areas and for coastal or oceanic areas. Reduced productivity is expected in Spanish waters, given their characteristics as subtropical or warm temperate seas. The changes will affect many groups of organisms, from phytoplankton and zooplankton to fish and algae. There will be changes in the marine trophic networks, affecting resource species, especially in their larval phase and in recruitment. Species distribution will change, with an increase in temperate waters and subtropical species and a decrease in boreal species. There will be a possible increase in invasive species. Marine cultures provided with no food supplement could be affected by the reduced marine productivity. Increases are to be expected in the appearance of species of toxic phytoplankton or parasites of cultivated species, favoured by the temperature increase in coastal waters. The areas and systems most vulnerable to climate change are benthic communities; fields of phanerogams will be the most affected.

Plant biodiversity

The direct impacts of climate change on plant biodiversity will occur through two antagonistic effects: warming and reduced hydric availability. The “Mediterraneisation” of the North of the Peninsula and the “aridification” in the South are the most significant tendencies. The biggest indirect impacts are those deriving from edaphic changes, changes in the fire regime and a rise in sea level. Interactions with other components of global change and the modification of interspecies interaction constitute another potential source of impacts for which evidence is now beginning to accumulate. High-mountain vegetation, forests and deciduous thickets sensitive to summer drought, sclerophyllous and lauroid forests in the South and Southwest of the Peninsula and coastal vegetation are among the most vulnerable types. Structural simplification and the predominance of local extinction over re-colonisation constitute recurring tendencies of the different impacts. The loss of floristic diversity is of particular relevance in Spain, given that our country contains a high proportion of Europe's plant diversity.

Animal biodiversity

Spain is possibly the EU's richest country with regard to animal species, and the one with the highest number of endemisms. Climate change will cause: 1) Phenological changes in populations, with advances (or delays) in the initiation of activity, arrival of migratory species or reproduction; 2) maladjustment between predators and prey due to differential responses to climate; 3) displacement in the distribution of terrestrial species northwards or towards greater altitudes, in some cases with a clear reduction of their distribution areas; in rivers, displacement of thermophilic species upstream and a decrease in the proportion of cold water species; in lakes and lagoons, altitude, latitude and depth have similar effects upon communities in relation with temperature; 4) greater virulence of parasites, and 5) an increase in populations of invasive species.

Hydric resources

In Spain, climate change will cause big decreases in water resources. For the 2030 horizon, we can expect average decreases in hydric rosurces in natural regime of between 5 and 14%, whereas for 2060 an average global reduction of hydric resources is expected of 17% on the Peninsula. These figures could exceed between 20 and 22% for the scenarios predicted for the end of the century. Along with this decrease in resources, an increase is expected in the interannual variability thereof. The impact will be noted more severely in the Guadiana, Canarias, Segura, Júcar, Guadalquivir, Sur and Balearic Isles river basins.

Soil resources

Much of Spain's territory is currently threatened by desertification processes, especially by the impact of forest fires and fertility loss in irrigated soils due to salinisation and erosion. The projected climate changes will exacerbate these problems in a generalised manner, especially in the areas of Spain with dry and semiarid Mediterranean climates. The projected climate changes will probably cause a carbon decrease in Spanish soils, which will negatively affect the physical, chemical and biological properties of the soils.

Forestry sector

Forests pests and diseases can play a fundamental role in the fragmentation of forest areas. Some perforating or defoliating species can complete up to two biological cycles per year or increase their colonisation area as a consequence of more benign winters.

The physiology of most forest species could be profoundly affected. There is a high risk that many of our forest ecosystems will become net carbon emitters during the second half of this century. Tip of mountain areas, the more xeric environments and riparian forests could become more vulnerable to climate change.

Agrarian sector

Changes in CO_2 concentrations, in air (and ground) temperature values, and variations in seasonal rainfall will have opposing and non-uniform effects upon Spain’s agricultural systems. Climate change could affect the ingestion and wellbeing of the livestock and, consequently, the profitability of livestock farming systems. From the point of view of animal health, we can expect to observe the effects of climate change in all parasitic and infectious processes the etiological agents or vectors of which have a close relationship with climate.

Coastal areas

The main problems related to climate change in Spain’s coastal areas are associated with a possible rise in mean sea level (MSL). Projections by the models vary from 10 to 68 cm for the end of the century. For the end of the century, a 50 cm rise in MSL can reasonably be expected, with 1 m in the most pessimistic scenario. With a generalised rise in MSL, the most vulnerable areas are deltas and confined and rigidized beaches. This could lead to the loss of many beaches, especially on the Cantabrian coast. Many coastal lowlands would be flooded (Ebro and Llobregat deltas, Manga del Mar Menor, Doñana coast), some of which might be built up.

Natural hazards of climatic origin

Flood risk

Hydrological variability in Atlantic basins will increase in the future as a result of the intensification of the positive phase of the NAO index. This might reduce the frequency of floods, although not the magnitude of these. In the Mediterranean and inland basins, the greater irregularity of the rainfall regimes will cause an increase in the irregularity of the regimes of floods and flash floods.

Slope instability risk

Landslides and avalanches are concentrated in the main mountain ranges, especially in the Pyrenees, and the Cantabrian and Betic ranges. Slope instability currently causes losses of hundreds of millions of Euros annually, especially in communication channels and, to a lesser extent, in population settlements. The number of deaths caused by landslides has dropped in the last few decades, but there has been an increase in those caused by avalanches as a result of the mountains being more frequented. While confirmation by more accurate climate models is being awaited, increased torrentiality will cause a greater number of surface landslides and debris flow, the effects of which could be exacerbated by changes in land uses and less plant cover. Consequently, increased erosion is expected on slopes, along with a loss of quality of surface waters, due to increased turbidity, and a higher rate of clogging in reservoirs.

Forest fires risk

Temperatures and soil moisture scarcity will increase, which will cause greater and more long-lasting desiccation of fuels. Fuel flammability will therefore increase. Mean danger indices and, in particular, the frequency of extreme situations will increase. The average duration of the fire-danger season will be prolonged. There will be more ignitions caused by lightening. There will be an increase in the frequency, intensity and magnitude of fires.

Energy sector

In a scenario of temperature increases and reduced rainfall, an increase is expected in the demand for electric energy, which should be covered without having to resort to hydraulic energy production, as this would be reduced; an increase in the demand for oil and natural gas is also predicted, along with reduced deposits of biomass (currently scarce). Only solar energy (in its different forms) would be favoured by the plausible increase in hours of insolation. If there were to be an increase in episodes of strong winds, there might also be an increase in the production of aeolic-generated electricity.

Tourism sector

The impacts of climate change on the geographic-tourism space could cause changes in the associated ecosystems. Water scarcity would cause problems related to the functionality or economic viability of certain destinations. Temperature increases could cause changes in some activity schedules, leading to more travel between seasons. A rise in sea level would threaten the current location of certain touristic resorts and the infrastructures thereof. These impacts would have a greater effect upon the more deteriorated areas with a greater combination of the different climatic effects. There might be a reduction in the average stay at each destination, a delay in the moment of deciding to travel and a change of destination, foreign tourists thus staying at home and nationals travelling to northern coasts or inland.

Insurance sector

The detection of the effects of climate change upon the Spanish insurance sector involves analysis of the claims rates for coverage of flooding, storms, frosts, hail and drought, damages being the branch most affected. Storms and flooding are the most numerous and costly events. Compensation for flooding in the 1971-2002 period increased, most likely due to the increase in the insurance index, in exposure and in insured capital. Statistics for agricultural insurance show that the eastern half of the Peninsula is the most sensitive to climate change.

Human health

From the point of view of the possible impacts upon human health, we would need to consider the effects on morbidity and mortality of extreme temperatures, fundamentally through heat waves, which have been indicated as the most frequent with regard to intensity and duration for the coming years. Furthermore, the foreseeable increase in fine particles and ozone will constitute the main impacts in relation to atmospheric pollution. To these impacts we must add the geographic spread to our country of pre-established vectors or the establishment of subtropical ones adapted for survival in cooler, drier climates.

Main recommendations for policies in a scenario of climate change in Spain

Terrestrial ecosystems

The management of terrestrial ecosystems should involve society as a whole and seek creative ways of financing activities aimed at mitigating effects and for restoration and research. The conservation of terrestrial ecosystems in a scenario of climate change clashes with many human activities, especially in relation to the use of natural resources like water. There is a need for integrated management of the multiple goods and services provided to us by terrestrial ecosystems.

Inland aquatic ecosystems

The possibilities of adaptation of CAE to climate change are limited. In order to mitigate the effects thereof, there is a need for water saving policies, improved water quality and an intensification of the measures for the conservation of the surrounding terrestrial environments. Given that new conflicts over water are to be expected as a result of climate change, it is reasonable to expect the conservation of CAE to be the easiest priority to ignore. The changes the CAE are really subjected will affect environmental conservation and the tourism sector, population protection, water supply and continental fisheries.

Marine ecosystems and the fisheries sector

The management of coastal marine ecosystems and of marine species should be considered from a multispecific and ecosystemic perspective. The search for solutions that mitigate the effects of direct human activity should be promoted, along with medium- or long-term follow-up of actions.

Plant biodiversity

Avoiding losses of biodiversity caused by the impacts of climate change requires global responses. The sectorial strategies designed require a broader geographic framework than that of regional or local administrations, upon which they currently depend. The network of protected spaces, conservation policy, ecological restoration, forest management, the regulation of livestock farming and hunting uses, land planning, environmental evaluation and education constitute the policies most involved in the challenge of providing responses to the impacts of climate change.

Animal biodiversity

The areas most vulnerable to climate change are coastal areas, wetlands and permanent water course which will become seasonal and seasonal ones that will have a more irregular flow or will even disappear, high mountain areas and moist pasturelands. Neither the displacement of distribution ranges (hypothesis I) nor rapid adaptation to new ecological conditions (hypothesis II) appear to constitute feasible solutions for most of the species studied. The main management solutions should include the design of nature reserves and parks interconnected by biological corridors. The network of protected areas should include latitudinal and altitudinal gradients in order to protect populations undergoing processes of geographic displacement as a result of climate change. The zones or areas especially sensitive to climate change should be identified, especially for species with no option for habitat displacement.

Hydric resources

The change will necessarily involve re-modelling and redefining new policies such as those related to science and technology, hydraulics, energy, agriculture, environment and land planning. We recommend continuing with the tradition of measurements established in Spain by means of control systems, which are generally well-established or being improved. However, the convenience should be highlighted of designing and establishing, or clearly improving, the water use control networks, in relation both to surface and groundwater, along with the flow gauge network in fountains and springs.

Soil resources

The reforestation of marginal, barren land and the practice of a type of agriculture aimed at soil conservation, along with an increase in organic carbon content and improved edaphic fertility, offer great possibilities with regard to counteracting the negative effects of climate change. The amendment of the PAC (Agenda 2000) offers possibilities for applying this principle. Soil quality should be taken into account in town planning and in any re-classification of use. The drafting of the *European Strategy for Soil Conservation* s should established the basis for the development of European regulations dealing with the conservation and sustainable use of soils.

Forestry sector

In view of the foreseeable changes, an adaptational strategy is recommendable. Clipping of the underbrush to reduce stump density has proved to be an efficient treatment that improves the response of these forests to climate change. Control and adjustment of exploitation turns and intensities should be considered as an option for optimising the response of the forest. Equally important is the careful selection of the origins of the seeds in reforestation, for appropriate management of genetic diversity.

Agarian sector

In agricultural systems, extensification or forestation should be favoured in areas with increased instability, or intensification of stabilisation by means of irrigation in other areas, along with the establishment of alternative crops or areas of compulsory fallow and new design of integral control of pests and diseases. In livestock farming, reduced carrying capacity should be favoured, along with the necessary changes in grazing management; there should be support for supplementing and adapting facilities. The farming of autochthonous species and vector control should be considered, due to their possible repercussions in relation to foreseeable pathologies.

Coastal areas

Immediate action is required in relation to the human factors affecting the stability of the coast, such as the maintenance of discharge and solid deposits by rivers as a solution to the “origin” of the problem (the lack of sedimentary material). As a solution to the “symptoms” of the problem (excessive retreat or mobility of the coast), we can indicate the stabilisation of beaches and dunes, the construction of structures for limiting the transport capacity of incoming waves and artificial deposits of sediments. Protection of natural values (strict land planning to ensure the maintenance and recovery of valuable areas) is vital. There is also a need to demarcate and inventory the areas and elements that could be affected by a rise in sea level, in order to define where to apply abandonment and retreat strategies, or ones related to protection.

Natural hazards of climatic origin

Flood risk

We must improve the quantification of risk and prevention in relation to climatology and land planning, especially in urban areas and tourist resorts, particularly in Mediterranean ones; we also need to improve catchment prediction systems.

Slope instability risk

Land and town planning, aimed at avoiding the areas most susceptible to slope instability constitute the best and most economical adaptational tool.

Forest fires risk

Policies on fire fighting, land and forest planning and training and information for the public should be adjusted to the new conditions. Management schemes based on the total exclusion of fire should be modified, providing the possibility to use fire as a tool for reducing the hazadousness of certain areas. Plans for conserving biodiversity or for combating desertification ought to incorporate the new scenarios of increasing fire-danger. Management of public spaces for recreational use should take into account the growing danger that approaches.

Energy sector

We seem to be following the right path with regard to energy policy, both in the EU and in our country, but our energy production, however, is far from being sustainable. We therefore need to study these policies in depth in order to adopt specific and additional measures for implementing strategies, in order to make our energy production sustainable, especially with regard to reducing emissions.

Tourism sector

Implications for public policies, from the incorporation of financial and fiscal aid and investment in specific infrastructures, to the modification of existing legislation on land planning, delimitation and uses, transport and even school schedules. All of this can be established through policies that reinforce investment in tourist infrastructures that capitalise on new opportunities in new areas, apart from the necessary restructuring of certain destinations and traditional products. This will require the vital public leadership and the active incorporation of all the companies in the tourism sector.

Insurance sector

We recommend the follow-up, in each regional autonomy, of the following measures, to be analysed and applied at national level: 1) Review of the Basic Construction and Design Regulations, and Review of Land Planning and Land Uses, in accordance with the climatic risk of each area and the foreseeable evolution of this. 2) Promotion of prevention education from primary school level. 3) Promotion of insurance as a prevention instrument. 4) Adaptation by the insurance market to the possible demands in a new scenario of climatic risk. 5) Analysis of the variability of agricultural policy in future climate scenarios.

Human health

There is a need for public health action plans based on early warning systems aimed at identifying risk situations before these occur, which involves an agile and reliable morbidity and mortality database. We need to apply and follow up European Directives relating to all the aspects that might affect human health, both in the short- and long-term. It is also of vital importance to promote and develop specific surveillance and control programmes related to vector-borne diseases, and to initiate activities aimed at increasing citizen awareness and participation in all the activities related to climate change and the implications thereof for human health.

Main needs for research and data for the detection of climate change

Terrestrial ecosystems

Among the main research needs, we can highlight the consolidation of long-term ecological follow-up networks, making as much use as possible of the existing and favouring the interdisciplinary participation of the scientific community, the study of interactions, both between environmental factors and between species and trophic levels, and the determination of minimum tolerance values (climatic, structural, functional) in systems vulnerable to climate change.

Inland aquatic ecosystems

The knowledge gaps are due to: 1) the lack of reliable long-term data series; 2) the fact that there is still scant information on the ecological state and biology of the most important species; 3) ignorance of hysteresis processes, and 4) the lack of knowledge of the possible effects on the SCAE of abrupt or gradual changes in terrestrial plant communities and in the geology of the catchments in which they are located. The research needs are many, as practically no study has been conducted of the relationship between CAE and climate change.

Marine ecosystems and the fisheries sector

We need to consolidate the long-term environmental and ecological follow-up networks, improving and making use of the existing ones. There is a need to promote Spanish participation in international programmes, along with research plans aimed at establishing the impacts of oceanic change upon species and ecosystems, from both a retroactive and prospective perspective.

Plant biodiversity

The three main lines of research to be promoted are: follow-up of the changes underway, including long-term programmes of measures in the field; the response by species and communities to changes and the design of predictive models, based on the information provided by the former and on the projections by climate models.

Animal biodiversity

There is a need to promote research on taxonomy, and research that includes long time series, at both specific and community level. More and better knowledge is required of faunistic diversity and the distribution thereof for the study of eco/geographic biodiversity patterns. We should not allow the deterioration or progressive disappearance of information sources, such as the phenological database on plants and animals (birds and insects) started in 1940 by the Agricultural Meteorological Service, belonging to the National Meteorology Institute (NMI).

Hydric resources

In relation to climate change, there is a vital need to conduct research aimed at improving predictions of rainfall and temperatures and of the spatial and temporal distributions thereof; of those tending to define methods of generation of data climate series based on scenarios; of those providing better and more reliable methods of evaluation of evaporation and evapotranspiration; the role of rainfall interception and use of water by plants, data for the more reliable establishment of aquifer recharge and the development of models for computerising calculations of inflow and storage; watershed management models.

Soil resources

An initial basic need in relation to edaphic resources involves the inventory thereof at a useful scale of management (at least 1:50.000), with which to establish an evaluation of their condition, to plan their management and project change tendencies. It would be of great use to compile the existing information, dispersed throughout institutions at different scales and in different formats, and to homogenise and computerise these using the criteria from the FAO-CSIC database. Long-term basic studies should be promoted in order to attempt to detect tendencies in the evolution of soils, along with responses to disturbances and to climate change, especially in relation to low-periodicity events.

Forestry sector

Among the most pressing needs for the future, we can highlight the need for more accurate knowledge of the subterranean of our forest species, to establish or consolidate networks for the observation and analysis of the ecophysiological factors determining regeneration and, as a whole, the response of the forest to environmental changes; another aim involves promoting the development and application of forest growth models, aimed at predicting the response by the forest to environmental changes or management patterns.

Agrarian sector

The development and implementation of dynamic models for simulating different crops, in order to describe the interception of solar radiation by leaves, the generation of biomass (aerial fraction and roots), water and nitrogen balances and the generation of yields. Data on the response by agriculture and livestock farming to climate changes in long time series aimed at predicting effects on production yield of the different farms. The development of simulation models to account for the behaviour of different pathogenic agents in relation to climate; their capacity for adaptation to the biotope and the seasonal dynamics of the different processes.

Coastal areas

There is a need for more detailed knowledge of past processes (with annual or ten-year resolution). There is also a need for further study of the impact that climate changes, in particular with regard to MSL and other driving factors such as waves, together with the corresponding morphodynamic change, could have on sensitive coastal ecosystems. There is a need for follow-up systems and systematic data collection of the necessary parameters in order to establish empirical relationships or to design and validate models. We need to learn of the impacts of climate change upon wind and wave regimes and on the circulation patterns affecting each area.

Natural hazards of climatic origin

Flood risk

Development of coupled climate-hydrology regional models in order to provide reliable scenarios of hydrological extremes, taking into consideration the particularities of the Atlantic and Mediterranean basins. Reconstruction of past floods and study of the gauging series, referring these to natural conditions.

Slope instability risk

There is a need for a complete inventory of landslides and better damage assessment, as this is much greater than the official figures. More in-depth study is needed of the relationships between rainfall events and the different types of landslides, in order to appropriately integrate them into the hydrological and mechanical models.

Forest fires risk

More detailed knowledge is needed of the interactions between drought, fire danger, the occurrence of fires and the response by the vegetation in adverse situations. We must learn of the synoptic conditions that set extreme events in motion, thus allowing to anticipate and prevent fires. Climatic scenarios are needed with suitable spatial and temporal resolution, as well as models of vegetation response. We require more in-depth knowledge of the sociology of fires. Detecting change in the occurrence of fires necessitates maintaining the EGIF database on forest fires of Spain, and availing of cartography of the fires in order to verify changes in the spatial or temporal patterns thereof.

Energy sector

There is a need for more in-depth knowledge of the possible effects of climate change on energy demand at regional level and according to economic sectors. All of this is due to different reasons: generalist scenarios of climate change could lead to big information losses; thus, we should establish whether the foreseeable increase in mean temperature will be homogeneous, or whether it will affect certain regions more than others; this obviously affects different local infrastructures; and with regard to the series of indicators proposed for the detection of climate change in relation to the energy sector, there is a need to design models that break down the different elements influencing the evolution of these indicators.

Tourism sector

Research needs focus on critical knowledge gaps: 1) Study of the current role of climate in Spain's tourism system and the impacts of climate change according to the most vulnerable zones and products, integrating the different scales of manifestation of the phenomenon. 2) Creation of systems of indicators of the climate change-tourism relationship in order to detect and measure this. 3) Design of management models for optimising the main adaptational options and implications for tourism policies. This involves setting up and maintaining a specific line of funding for research projects, with explicit programmes dealing with this theme, to be integrated into the National R+D+I Plan.

Insurance sector

Greater availability in time, and adjusted to the needs of the sector, of meteorological and climatic data. Didactic explanations of the scenarios designed by the IPCC and the consequences of these. Experimental studies of the vulnerability of structures and crops in the different geographic areas to the main meteorological and climatic phenomena in their most extreme manifestations. Detailed statistics, prolonged in time, related to claims on the Spanish insurance market, according both to areas and to catastrophic events. Development of catastrophe models, combining risk and the financial parameters of the insurance and reinsurance sectors, in order to recreate historic and to estimate future losses.

Human health

There is a vital need for a more in-depth evaluation than the one conducted here of the possible impact on health of climate change in Spain, as has been conducted in other countries. This evaluation should include the quantitative assessment of the impacts upon health, taking into account the different scenarios of climate change and predictions of the demographic structure of our country. This would involve following the recommendations and methodology that the World health Organisation has developed in order to establish the degree of vulnerability in relation to human health and to make the necessary adaptations with regard to human health and climate change.

1. THE CLIMATE OF SPAIN: PAST, PRESENT AND SCENARIOS FOR THE 21ST CENTURY

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ABSTRACT

Due to its complex orography and geographic situation, Spain has great climatic variability. The spatial differences of annual mean temperature values surpass 18ºC on the Peninsula and the average annual accumulated precipitation ranges from barely 150 mm to over 2500 mm.

To this we must add the high interannual climatic variability and the noteworthy range of extreme daily values. Thus, for example, rainfall variability reaches rates of over 20% in Mediterranean regions and the Canary Isles, and the sequences of consecutive rainless days can exceed 4 months in the South. Interannual variability is fundamentally conditioned by different patterns of general atmospheric circulation in the northern Hemisphere, among which we can highlight the North Atlantic (NAO index). Furthermore, extreme daily temperature values cover an interval of between –40ºC and +50ºC and daily precipitation maximums can exceed 500 mm.

Analysis of recent temperature tendencies enable us to confirm that there has been quite a general rise in annual mean temperature since half-way through the 70s of the XX century, by an amount slightly higher than what has been observed at global scale, warming being more evident in winter. Furthermore, the complex spatial distribution of precipitation and the high temporal variability of this do not enable us to define any general tendency. However, abundant results indicate a downward tendency in the South of the Iberian Peninsula and in the Canary Isles in the second half of the XX century, which appears to tally with the positive tendency of the NAO index observed in the last few decades. There are no conclusive results, either, of the evolution of the number of days with heavy rainfall.

The tendency of future climate resulting from the application of global climate models is affected by different sources of uncertainty. Among these, we can highlight the evolution of global anthopogenic emissions of greenhouse gasses (GHGs) and of sulphate aerosols. For this reason, the IPCC has established a set of emission scenarios (SRES), according to different suppositions regarding population growth, the evolution of socio-economic activities and of technological progress throughout the XXI century. This report only considered the scenarios known as A2 and B2. The former corresponds to an evolution of GHGs that is increasing more rapidly than the latter. Thus, in A2, the global CO_2 concentration would reach 850 ppm in the year 2100, 120% higher than at present, and in B2 around 760 ppm, approximately double the present value.

Taking into consideration the average results of the set of six global climate models, temperature increases are projected on the Iberian Peninsula which are essentially uniform throughout the XXI century, with an average tendency of 1.2ºC every 30 years in winter and of 2ºC every 30 years in summer for scenario A2, and of 1.1ºC and 1.8ºC respectively, for scenario B2. With regard to precipitation, the change tendencies throughout the century are generally not uniform, with notable discrepancies among the global models, which makes the result less reliable. All of them, however, coincide in a significant reduction of total annual precipitation, somewhat greater in scenario A2 than in B2. These reductions are maximum in spring and somewhat lower in summer.

The low spatial resolution of the global climate models do not allow for spatial discrimination of the projection of climate change in Spain, because of its relatively small geographic area. For this reason, we considered the results provided by a regional climate model, with a resolution of 50x50 km2, nested in one of the previous global models. It should be pointed out, however, that the projections with the regional model presented here only refer to the last third of a century (2070-2100) and correspond to the regionalisation of the climate change simulated by one

single global model. For this reason, although they present greater spatial detail and the results essentially coincide with that of eight other European regional models nested in the same global model, the reliability of the results should theoretically be considered lower than those of the average of the ensemble of the six global models.

The most relevant changes projected by the regional model for the last third of the century in relation to present climate can be summarised in the following points:

a) On the inland Peninsula, the temperature increases in relation to the present climate in scenario A2 reach values of between 5ºC and 7ºC in summer and between 3ºC and 4ºC in winter. In scenario B2, the distribution of warming is similar to that of scenario A2, but generally 1ºC less intense. On the coast of the Peninsula and of the Balearic Isles, the warming projected is around 2ºC less than that on the inland Peninsula in all the seasons of the year, and in the Canary Isles, around 3ºC less in summer and 2ºC less in winter.

b) The changes projected for accumulated precipitation are spatially more heterogeneous. In winter there are slight increases in the Northwest and slight decreases in the Southwest in both emission scenarios. In spring there are greater generalised decreases, although somewhat higher in scenario A2 than in B2. In summer, the increase in precipitation is maximum throughout the whole territory, except in the Canary isles. In autumn, a slight increase in the Northeast is projected for scenario A2, and a decrease in the Southwest, both of these less intense than in scenario B2.

c) An increase is projected in the range and frequency of monthly temperature anomalies in future climate in relation to the present climate. Although this increase is not noted in a regular manner throughout the whole territory, in all the seasons of the year and in the two emission scenarios the increases in range remain at around 20%. Furthermore, no significant alterations have been observed in the frequency of monthly precipitation anomalies, although this conclusion is especially questionable.

d) The frequency of days with extreme maximum temperatures on the Iberian peninsula tends to increase significantly in spring and, to a lesser degree, also in autumn, whereas in the Balearic and Canary Isles, no appreciable changes have been noted, the same as what occurs in the other two seasons of the year throughout the whole territory. The frequency of days with extreme minimum temperatures on the Peninsula presents a downward tendency.

Considering the set of results of climate change projected throughout the XXI century for Spain by the different climate models considered in this report, we can arrange their degree of reliability, in a descending order, in the following manner: 1º Progressive tendency towards and increase in average temperatures throughout the century. 2º More accelerated tendency towards warming in the more accelerated emission scenarios (A2). 3º Increases in average temperature are significantly greater in summer months than in winter ones, with intermediate values in the remaining months. 4º Warming in summer is greater in inland areas than close to the coast or on the islands. 5º Generalised tendency towards less annual accumulated rainfall in both emission scenarios throughout the century. 6º Greater range and frequency of monthly temperature anomalies in relation to the present climate. 7º Greater frequency of days with extreme maximum temperatures on the Peninsula, particularly in summer. 8º The greater reduction of precipitation on the Peninsula is projected in the months of spring in both emissions scenarios for the last third of the century. 9º Increase in precipitation in the West of the Peninsula in winter and in the Northwest in autumn. 10º Changes in precipitation are in general greater in the more accelerated emission scenario (A2).

1.1. CLIMATE EVOLUTION IN THE PAST

At scales of thousands of years, tens of thousands and even greater, Spain's climate has followed the general patterns laid out by natural fluctuations and global climate changes. The glacial periods – the best known changes of the geological past – have left numerous visible marks of the landscape and varied palaeoclimatic records. Climatic changes have, however, been expressed locally, as a result of modulation of global change by the geographic factors and physiographic variables of the different regions of Spain. Numerous palynological records in lakes pay witness to changes in vegetation like, for example, those obtained in Padul (Granada) (Pons and Reille 1988), Banyoles (Gerona) (Pérez-Obiol and Julià 1994) and Sanabria (Zamora) (Sobrino *et al.* 2004). These analyses have shown that the climate in Spain has repeatedly changed as a result of natural processes, as has occurred all over the planet, and in certain periods in the past, there have been climatic conditions radically different from the present ones. Thus, as an example, polar waters and probably icebergs entered the Mediterranean through the Straits of Gibraltar on many occasions during the last glacial period (Cacho *et al.* 1999).

The glacial periods, which must have been characterised by temperatures several degrees below the current ones, were much longer than the interglacial ones, and while they lasted, there were abrupt climatic oscillations at geological scale, such as the *Dansgaard-Oeschger* warm cycles during the last glaciation (between 110,000 and 10,000 years BP). These rapid oscillations were caused by changes in oceanic currents, which had a great impact on the Iberian environment, as can be seen in the profound changes in the vegetation (Burjachs and Julià 1994). The relevance of these episodes demonstrates the existence of sudden changes in climate, which, in spite of their distant origin, are capable of spreading globally. Indeed, the environmental conditions of the Iberian Peninsula and of the Mediterranean basin have been very sensitive to the climatic variability of the North Atlantic region. The climatic variability of the Peninsula has been closely related to changes in marine circulation, although different areas have shown responses that have been attenuated to a greater or lesser degree, depending on their location (Sánchez-Goñi *et al.* 2002).

The transitions from glacial periods to interglacial ones were rapid on a geological scale, with occasional abrupt recessions to quasiglacial conditions, as occurred during the *Younger Dryas* episode (between 13,000 and 11,600 years BP) in most of Europe, although this oscillation may not have affected the whole Iberian Peninsula (Pérez-Obiol and Julià 1994; Allen *et al.* 1996; Carrión 2002). The interglacial periods, like the one we have been in for the last 10,000 years (the Holocene) are warmer, in comparison to the glacial periods, and climatically more regular, although there have been some brief fluctuations (Leira and Santos 2002).

Climatic conditions during the Holocene have not remained totally constant, either, and different studies have shown that, in general terms, Iberian climates have become more arid and temperatures have been rising gradually (Araus, *et al.* 1997; Jalut *et al.* 1997; Jalut *et al.* 2000; Davis *et al.* 2003; Rimbu *et al.* 2003). Some of these authors suggest that this tendency is probably the opposite to what has occurred in other parts of Europe and the North Atlantic.

The climatic scenario for just over the last thousand years on the Iberian Peninsula has been characterised, in general terms, by a warm episode during the Middle Ages, between IX and XIII-XIV centuries, accompanied by relatively abundant and regular precipitations. The medieval warming period was followed by an episode of relative cooling and increased pluviometric irregularity between the XIV and XIX centuries. Dendroclimatic studies carried out on the Iberian Peninsula have permitted the reconstruction, in a sporadic manner since the XII century, and more continued since the XV century, of values of mean annual temperature and rainfall in several points of the territory. Temporal analysis of the variability of these series, including varying degrees of extreme values, has demonstrated the alternation of periods with very differentiated climatic characteristics (Creus *et al.* 1997; Saz and Creus 1999; Saz 2003)

(Figure 1.1). Thus, the climate in the initial centuries was characterised by high rainfall and temperature values, with a very regular regime that lasted well into the XIV century, when both variables started to show a notable downward trend and an increase in the frequency of extreme values. This behaviour was the prelude to the start of a very variable and particularly cold climate phase, which reached its peak in the XVII century and lasted until the end of the XVIII and the first decades of the XIX. It corresponds to the phase known as the Little Ice Age (LIA), during which climatic variability was very high, while, at the same time, there were pulses of differing intensity that aggravated its characteristics. The LIA has also been identified on the Iberian Peninsula with the use of coastal marine records (Luque and Julià 2002), and lacustrian (Desprat *et al.* 2003) and documentary ones, using in this case, rogation "pro pluviam" records and ones related to claims for flood damage (Martín-Vide and Barriendos 1995; Barriendos and Martín-Vide 1998). One of the most notable pulses during the LIA, with increased droughts and torrential rainfall in the eastern Mediterranean, took place at the end of the XVIII century (Barriendos and Llasat 2003).

With regard to climatic risks, in certain periods of the LIA these were more frequent and of greater magnitude than during the XX century, with a noteworthy impact on the societies of the time. The recent period, from the middle of the XIX century to the present has involved, from the secular point of view and with reference to the LIA, a return to conditions of greater climatic regularity.

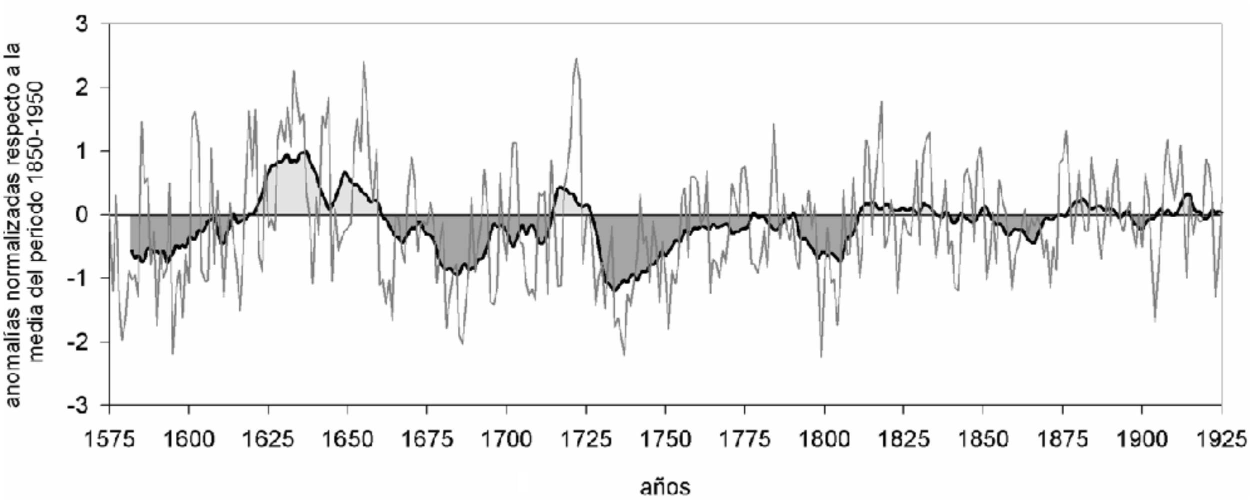

Fig. 1.1. *Annual precipitation anomalies in NW Spain (1575-1925) –smooth curve using 15-year moving averages (By J.Creus).*

1.2. THE PRESENT CLIMATE

1.2.1. Temperature

a) Mean annual temperature

Although the distribution of the mean annual isotherms provides quite a good reproduction of the hypsometric map, the latitudinal differences between northern and southern Spain, even excluding the Canary Isles, along with the different characteristics of the Atlantic ocean and the Mediterranean sea, give rise to certain differences. The main spatial values and models of mean annual temperature for the Iberian Peninsula and the Balearic Isles are the following: the value for sea level ranges from just below 14ºC on points of the coast of Cantabria to over 18ºC in the southern Mediterranean and the South Atlantic; 2) along the eastern Mediterranean coast, mean annual temperature ranges from 15ºC in some sectors of the Catalonian coast to 18ºC on the coast of Almeria, whereas on the Balearic Isles, the values next to the sea are between 16 and 18ºC; 3) the mean annual temperature can be negative above an altitude of 2,800 m in the northern half of the Peninsula (Pyrenees) and in shaded areas above 3,100 m in the south (sierra Nevada); 4) the northern plateau presents values of between 10 and 12.5ºC and the southern plateau, between 12.5 and 15ºC, in general; 5) the lowlands of the Ebro basin have mean annual temperatures a little above 14ºC, those of the Guadalquivir valley are between 17 and 18ºC and those of Extremadura are slightly over 16ºC; 6) the values decrease in the coast-inland direction; 7) the values increase from North to South, at equal altitude; 8) inland, values decrease from West to East (Figure 1.2).

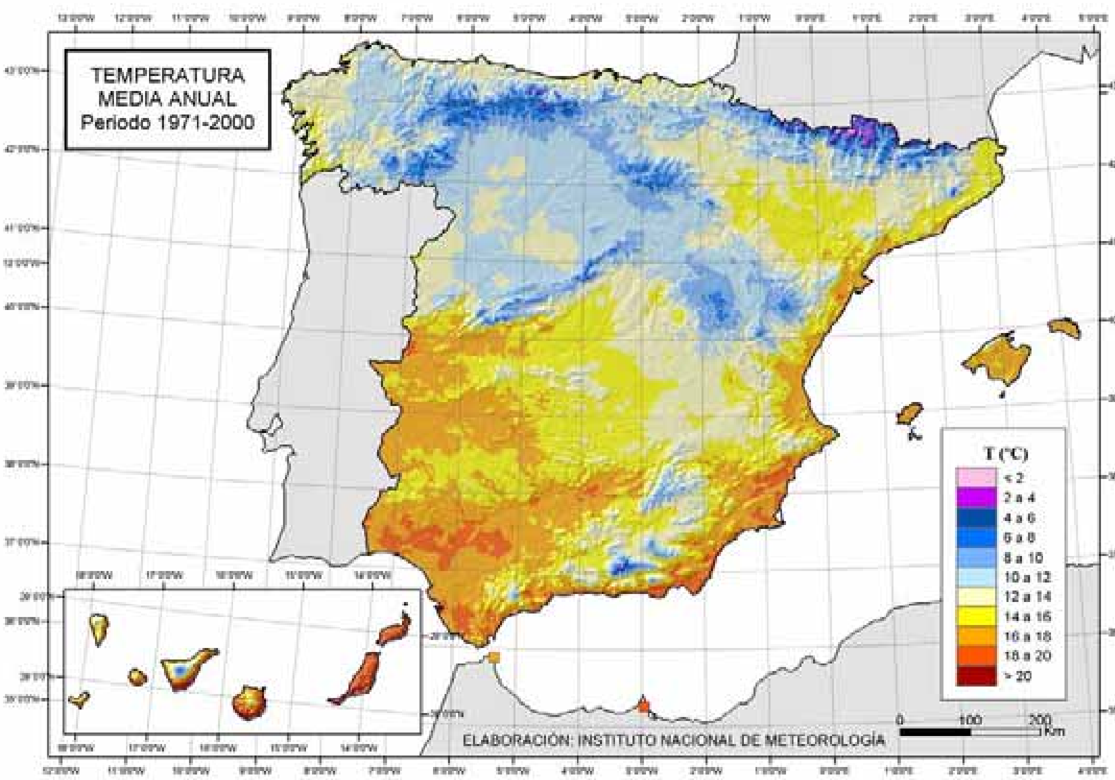

Fig. 1.2. *Annual mean temperature (ºC)(1971-2000) (Source: Spanish Meteorological Institute).*

The temperature difference of slightly over 4ºC between the mean annual temperatures of the northern and southern coasts of the Iberian Peninsula constitute a latitudinal gradient of just over 1ºC/200 km. On the coast of North Africa, Ceuta and Melilla present values comparable to those of the south coast of the Peninsula. On the Canary Isles, temperatures are appreciably higher than in the rest of Spain at equal altitude, surpassing 20ºC, and even reaching 21ºC on the coasts. In short, the mean annual temperatures tally with global averages, but they show considerable contrasts between the higher, northern lands and the lower, southern ones.

b) Mean temperatures in January and July

January presents the lowest mean monthly temperature, with the exception of certain parts of the Canary Isles and some capes in Galicia, whereas February can be one tenth of a degree lower than January. On the other hand, the highest monthly averages are not exclusive to July, but rather, in many of the coastal observatories like the Balearic Isles, Canary Isles, Ceuta and Melilla, these are registered in August and are due to the thermal inertia of the sea water, although these show little difference from the preceding month. The main characteristics of the isotherm map for the month of January can be summarised as follows: 1) the 6ºC isotherm encompasses the whole northern half of the Peninsula, with the exception of the coastal and pre-coastal fringe below 500 m altitude; 2) in the southern half of the Peninsula, the same isotherm encompasses Madrid, much of Castilla-La Mancha, the Sierra Morena mountains, some inland regions of the Valencia Regional Autonomy, the main Sierra Bética and Penibética mountains, as well as the higher parts of Extremadura, Majorca and Tenerife; 3) the 12ºC isotherm appears on the southern Mediterranean and South Atlantic coasts, Ceuta, Melilla and below around 700 m on the Canary Isles.

The main characteristics of the isotherm map for the month of July can be summarised as follows: 1) the 24ºC isotherm covers a large area in the southern half of Spain, with the exception of an eastern strip comprising Castilla-La Mancha, along with the Cordillera Ibérica mountains, some parts of inland Valencia, the main Sierra Béticas mountains and some parts of the Montes de Toledo and Sierra Morena mountains; 2) temperatures of over 24ºC are also reached, in the northern half, in the lower lands of the Ebro basin; 3) the 16ºC isotherm only appears in the Cordillera Cantábrica mountains and at the higher levels of the Galaico Massif and the Montes de León mountains, of the Pyrenees and of the Ibérica and Central mountain ranges of Sierra Nevada and of the Teide; 4) the Cantabria coast in the north does not reach 20ºC. Summertime is only cool in the higher mountain ranges and on the coast of Cantabria, whereas much of the southern half of the Peninsula can be considered to be very hot. In the Mediterranean course of the Guadalquivir river, between Jaén and Seville, a monthly average of 27ºC is surpassed.

c) Extreme temperatures

It is well known that the 40ºC threshold is surpassed every summer in some capital cities of Andalucia, such as Córdoba and Seville, as well as in other parts of the southern half of Spain. Even this value has been greatly surpassed on occasions. Thus, Écija (Seville) has recorded on different occasions the temperature of 47ºC (July 7th 1959, several days in July 1967, etc.). Likewise, in Seville 47ºC has been reached (August 6th 1946). During the heat wave in July 1995, Seville and Córdoba reached 46.6ºC. The record of 51ºC registered on July 30th, 1876 in Seville is doubtful, as well as other values of over 50ºC in smaller observatories. We must consider, however, in view of the existing records, that on certain occasions, a temperature of 50ºC has been reached in some parts of the Guadalquivir basin.

Temperatures of 40ºC are not exclusive to Andalucia, and, although less frequently, they have been reached and surpassed in Castilla-La Mancha, Extremadura and Murcia, and, on rarer occasions, in the lowlands and mid-altitude lands of Navarre, La Rioja, Aragón, Valencia, Alicante, Mallorca, inland Catalonia, lowlands of Orense and certain point of the Rías Bajas, towns of Madrid, Tenerife and eastern islands of the Canary Isles. The maximum absolute temperature even of Bilbao has exceeded 40ºC, under the influence of southern conditions. The 45ºC isotherm can be considered as being exclusive to the Guadalquivir valley. Although the clearest and most general atmospheric heat wave situation with temperatures of over 40ºC is due to advection of air from the Sahara in the lower layers of the troposphere, in some parts of Spain this threshold has been reached in other situations (*föhn* – type westerly wind on the Valencia coast, southerly wind, also of the *föhn* on the Basque coast, etc.).

With regard to minimum absolute temperatures, on the coasts of the Mediterranean, the Peninsula and Balearic Isles, the coasts of the South Atlantic and the lowlands of the Canaries, frost is infrequent or even non-existent. But the continentality and the altitudes of the inland Peninsula and of the mountain ranges on occasions permit very low minimums. The observatories of Castilla- La Mancha and Castilla y León have recorded minimum temperatures of below –10ºC and, in some places, less than –20ºC, over a thirty year period. Temperatures of below –10ºC can also be registered in the Ebro basin, the Intrabetic *hoyas* (topographic depression), such as Granada, inland Galicia and Cataluña, as far as the coast of Guipuzcoa.

Likewise, at the higher levels of the main mountain ranges, temperatures have dropped below the aforementioned thresholds. During the last international period, the aerodromes of Los Llanos (Albacete), at only 704 m altitude, recorded –24,0ºC, Villafría (Burgos), -22,0ºC, Vitoria, little over 500 m, -21,0ºC, and Matacán (Salamanca), -20,0ºC. The official record for minimum temperature in Spain is held by Estany Gento, in the Pyrenees of Lérida, at an altitude of 2120 m, with –32ºC, on February 2nd 1956, during one of the harshest cold spells of the XX century. Temperatures of –40ºC have probably been reached, at some stage, on the highest summits of the Aragón Pyrenees. Set in an area of the Cordillera Ibérica mountains between Zaragoza, Teruel and Guadalajara are some of the coldest parts of Spain in winter, if we take into account their relatively modest altitude, between 850 and 1,100 m. The Calamocha and Molina de Aragón observatories have recorded values of between –28ºC and –30ºC.

d) Mean annual temperature range and continentality

The annual mean range (difference between the mean temperatures of the hottest and coldest month) which is a good index of continentality, is notably high on the Plateau, especially the southern part, and the in the Ebro basin. In some parts of the southern Plateau, an annual mean range of 20ºC can be surpassed. Values of 18ºC and even higher are common in the lowlands of the Ebro valley and its tributaries, and of between 16 and 17ºC on the northern plateau. To the contrary, the coastal areas of the Canary Isles have minimum annual mean ranges, due to their insularity and low latitude. Thus, on the coasts of the Canaries, the hottest month is differentiated from the coldest one by between only 5ºC and 7ºC. On the Peninsula the lower level of continentality, or the greater oceanic influence can be found on the coasts of La Coruña, and is around 9ºC. To the contrary, the eastern Mediterranean coast and that of the Balearic Isles present a relatively high range, around 14ºC due to the influence of a sea that is practically closed-off and surrounded by highlands.

1.2.2. Rainfall

a) Mean annual rainfall

Rainfall is the most important climatic element in Spain, both from the point of view of climate and as a resource, given the modest amount that falls in much of the territory and its high temporal and spatial variability. The mean annual total has traditionally been used to distinguish three large zones: rainy Spain, dry Spain and semiarid Spain. The dividing line between the rainy and dry parts of Spain is usually established by the 800 mm isoyet and, in some cases, the 600 mm or intermediate one. The dividing line between dry Spain and semiarid Spain is established by the thresholds of 300 or 350 mm. The representation of three categories is not perfectly separated in space, but is interspersed in numerous sectors. Thus, the map of mean annual rainfall in Spain is a very complex one, with many enclaves with high or low pluviometry inserted into regions presenting the opposite sign (Figure 1.3).

Rainy Spain fundamentally comprises, in a continuous manner, almost all of the North and Northwest of the country. In most cases, mean values are above 1,000 mm, and in the sectors most exposed to wet maritime airflow, 2,000 mm can be surpassed. There are also numerous sectors of the peninsula and even of the islands, that surpass the threshold of 800 mm, almost always in mountain ranges. The largest area, dry Spain, occupies a huge area in the centre of the Iberian Peninsula, taking in the flatlands of the two Plateaus, the lowlands of the Ebro basin, the Guadalquivir Basin, and much of the eastern coast, except for the Southeast and the southern Mediterranean and South Atlantic coasts. Also belonging to dry Spain are the Balearic Isles, excepting the Tramuntana mountains in Majorca, some of the highlands and other mid-level ones on the Canaries, Ceuta and Melilla. Values of around 500 mm are quite frequent in dry Spain. Semiarid Spain is represented mainly by the Southeast of the Peninsula, that is, much of the province of Almeria and sectors of Murcia, Granada and Alicante. There are also some small enclaves in the Ebro and Duero basins, as well as in Lanzarote, Fuerteventura and the lowlands of the remaining Canary Isles, except La Palma.

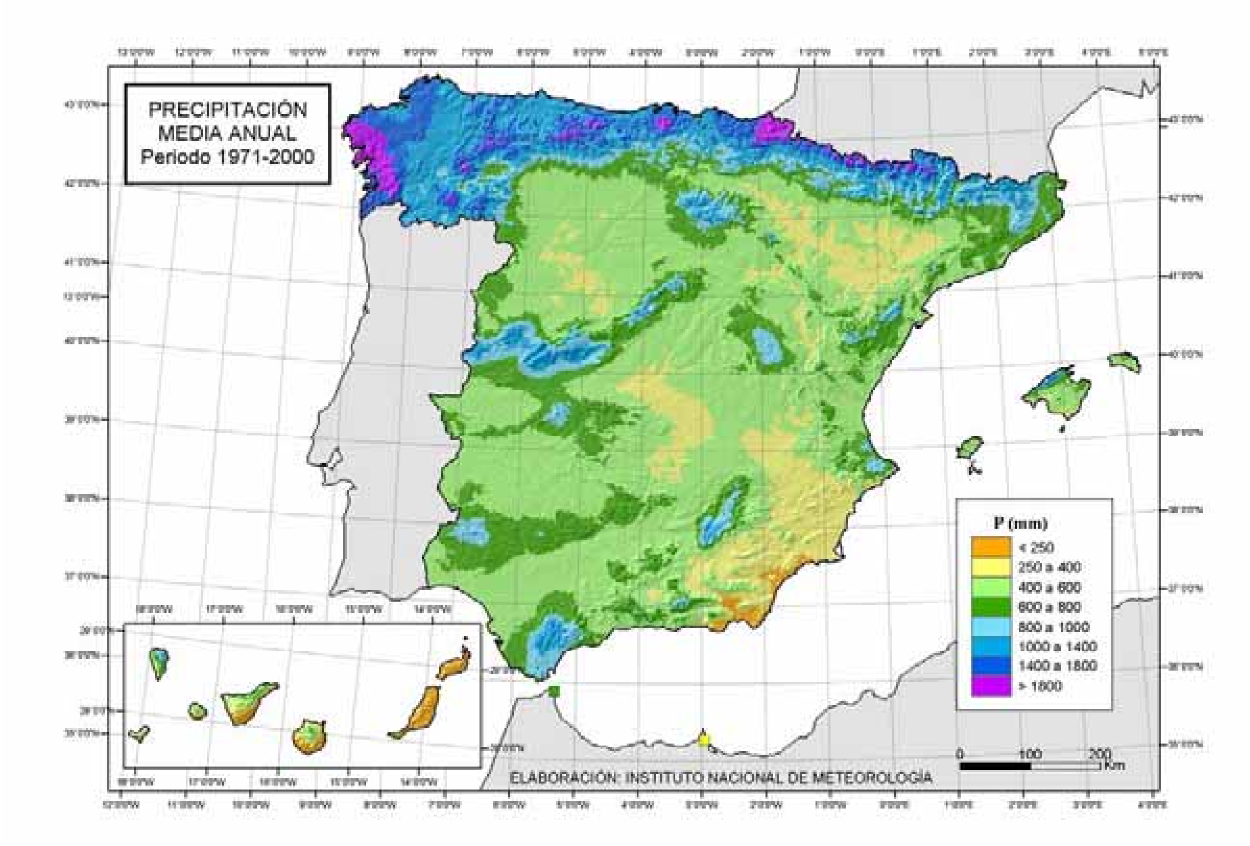

Fig. 1.3. *Annual mean precipitation (mm) (1971-2000) (Source: Spanish Meteorological Institute).*

At joint scale, annual rainfall on the Iberian Peninsula decreases from North to South and from West to East, so that on an imaginary diagonal line running from Galicia to Almeria, we can see the extreme contrast with regard to rainfall. In the Canary Isles, rainfall also diminishes from North to South on each island, and from West to East in the archipelago. In the Balearic Isles, rainfall generally increases from Southwest to Northeast.

In peninsular Spain the mean annual volume of rainfall during the 1961-1990 period was estimated at 327.286 x10^6 m^3, which is an average height of 665 mm. The lowest value for peninsular Spain corresponds to Cabo de Gata (Almería), between 125 and 150 mm, depending on the period analysed, whereas in certain well-exposed parts of rainy Spain, values can exceed 2,500 mm. This means that the latter values are over 20 times greater the former. On the Balearic Isles, the extreme values are around 1,400 mm, in the Tramuntana mountains, and little over 300 mm in some parts of Formentera. On the Canaries, the range of values is approximately between 1,100 and 1,300 mm, in the Northeast of La Palma, and less than 100 mm in sectors of Lanzarote, Fuerteventura and on the south of the other islands, except for La Palma.

b) Interannual rainfall variability

In accordance with Mediterranean climates, rainfall in much of Spain is characterised by its high interannual variability. The 20% threshold for the annual variation coefficient enables us to establish the dividing line between Mediterranean climates and mid-latitude marine west coast ones on the Iberian Peninsula. In the Mar Menor sea, and in certain other parts of the east coast, the annual variation coefficient reaches 40%, which is a very high interannual variability. On the Canary Isles it also exceeds this value (Figure 1.4).

c) Seasonal rainfall regime

One of the most surprising climatic facts in mainland Spain is the extraordinary variation in seasonal rainfall regimes. Thus, there is no general rainy season, and not even a dry one, although, in this case, a high percentage of the territory is subjected to dry or very dry summers. On the two archipelagos, apart from summer minimums without exception, the maximum is well defined, in autumn on the Balearic Isles and in winter in the Canaries.

The seasonal rainfall regimes enable us to draw up a complex and varied spatial mosaic. In Spain, there are no less than 13 seasonal rainfall regimes of the 24 theoretically possible ones, resulting from the decreasing arrangement of the mean quantities of the four seasons (Table 1.1).

Table 1.1. *Global conclusions in relation to seasonal rainfall regimes in Spain (Martín Vide and Olcina 2001)*

Conclusions	*Regimes represented*	*Main distribution areas*
Winter max. ⇒ summer min.	WSASU WASSU	Atlantic, Cantabria and Southern Mediterranean sides and Canaries
Summer max. ⇒ winter min.	SUASW, SUSAW	Catalonia Pyrenees and one sector of the Cordillera Ibérica mountains (Jiloca-Guadalaviar)
Autumn max.⇒spring min.	ASWSU, ASSUW, AWSSU, ASUSW	Eastern Mediterranean side and Balearic Isles
Spring max⇒autumn min.	SAWSU, SASUW, SWASU, SSUAW, SSUWA (exception)	Inland peninsula
	Balanced	Valle de Arán

W: winter (DJF); S: spring (MAM); SU: summer (JJA); A: autumn (SON)

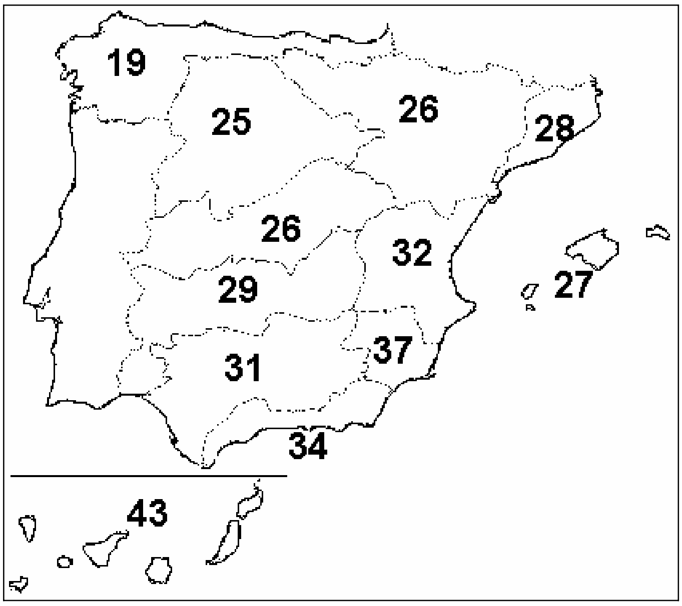

Fig. 1.4. *Mean coefficient of variation (%) of annual rainfall according to watersheds, based on data from 274 stations (basic period 1940-1989). (Martín-Vide 1996)*

In the Arán valley rainfall is distributed so evenly over the four seasons, that we can speak of a balanced regime. The regimes of the first and second groups are opposed, assuming that the ones presenting the summer maximum are constituted by the total inversion of the typical Mediterranean regime and the of the west coast marine ones. The lack of wintertime rainfall in parts of the eastern peninsula constitutes a unique range of seasonal regimes in Spain. Summer is extremely dry in southern Spain, including the Canary Isles. The percentage of summer, compared with the annual total, is less than 3% in the Straits of Gibraltar and throughout almost all the Canary Isles.

d) Frequency of rainfall and dry spells

For Peninsular Spain we can establish the following spatial values and patterns in relation to the mean annual number of days with appreciable rainfall: 1) it shows a clear decrease from North to South; 2) there is generally a certain decrease from West to East; 3) it presents relative maximums over the main mountain ranges; 4) it exceeds 100 days, almost without exception, further north than 40ºN, in Galicia, the Montes de León, the northern coast and the Cordillera Cantábrica, the highest parts of the Pyrenees and pre-Pyrenees and of the Central and Ibérica mountains, La Rioja and much of the northern Plateau; 5) it does not reach 50 days in the most arid sector to the Southeast of the Peninsula; 6) it barely reached 20 days in parts of southern Fuerteventura, Gran Canaria and Tenerife; and 7) the maximum is found in the eastern extreme of the Cantabrian fringe (San Sebastián, 188.0 days, in the 1951-1990 period).

In general, much of Spain, with the exception of the rainy northern fringe and the semiarid areas, presents an annual percentage of days of rainfall of between 15 and 35 %. If we use the threshold of 1 mm to consider one day of rainfall, part of the Southeast will total less than 30 days a year, whereas in the north, a total of 140 days can be surpassed. Consequently, the frequency of rainfall in much of Spain, with the exception of Galicia, the Cantabrian fringe, the western Pyrenees and nearby sectors, can be considered to be relatively low or very low.

The seasonal distribution of rainy days shows greater regularity and generality than the amounts. Winter and spring together are the seasons with the highest frequency of rainfall and summer has the least amount of rainy days. The lower the latitude, the lower the frequency of rainfall in summer.

The sequences of consecutive dry days can be very long in southern Spain, not only in the hotter half of the year, and this fact reflects the seriousness of droughts (Figure 1.5). In the 1951-1990 period, with the 0.1mm threshold, dry periods of over 4 months have been recorded in observatories in Andalucia, Extremadura and Castilla la Mancha, some of these lasting for over 5 months in Málaga, Almería and Huelva.

In much of Spain, snow is an infrequent phenomenon; the number of days with snow is only relevant in the big mountain ranges of the peninsula. Together, the spatial patterns and values most indicated in relation to the annual average number of days are: 1) altitude is the most decisive factor, so that, while snow is a rare phenomenon at sea level, with less than 5 days' occurrence, above around one thousand metres on the Iberian Peninsula and the Balearic Isles, and above around 2,000 on the Canary Isles, several days are always registered on the solid hydrometeor, reaching an average of ten or more; 2) the whole Spanish coastline, except for Cantabria, part of the Catalonia coast and the coast of Menorca, have snow for less than one day a year; 3) snow is practically unheard of on the lower, southernmost lands of Cadiz, in Ceuta or Melilla, and below around 1,200 m in the Canaries; 4) snow is more frequent in the northern half of the Peninsula than in the southern half; above around 1,800 m in the former and above 2,300 in the latter, there is a higher number of days with snow than rainy days; 5) In the Balearic Isles, the snow only makes an appearance on the summits of sierra Tramuntana, in

Majorca and 6) in the Canary Isles, snow only appears at the highest elevations of Tenerife, La Palma and Gran Canaria.

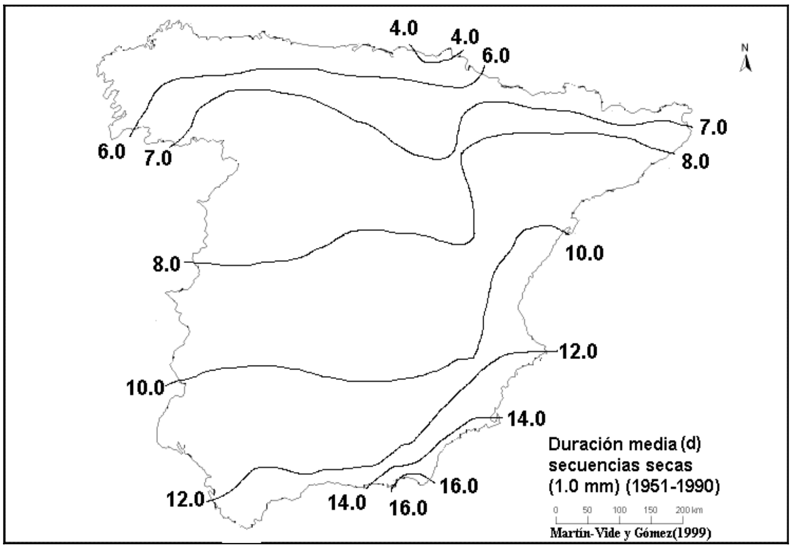

Fig. 1.5. *Average duration of sequences of dry days, with a threshold of 1.0 mm, in the 1951-1990 period (Martín-Vide and Gómez 1999).*

The number of days on which the snow settles presents very low values, except in the higher mountain ranges, where the snow layer can persist for quite a few days. The Pyrenees are, by far, the area with the biggest amount and longest duration of snow, which, above 3,000 m, does not melt in summer, allowing for the existence of small glaciers. Winter is the season with most snow. In the northern half of the Peninsula, above about one thousand metres, only the three summer months escape precipitation in the form of snow. On the summits of the Pyrenees, snow can fall in mid-summer.

Hail is an infrequent phenomenon, with an average occurrence of less than 5 days a year in most of Spain, but not without serious economic consequences for the agricultural sector. Even averages of less than one day are common in Andalucia and in the Canaries, the least affected regions. Northern Spain is, on the other hand, the region most affected by hail, with the highest number of days, 10 or more in La Coruña, Asturias and Cantabria, although some inland regions of the Valencia Regional Autonomy and of the Ebro valley, with fruit and vegetable crops very sensitive to hail suffer greater damage and economic losses. The hail calendar in Spain is dual: in much of the country, the hotter months of the year, from spring to autumn, the one with the greatest number of days with hail, caused by storms, whereas in the northernmost fringe the cold months present a greater frequency, associated with cold fronts.

e) Rainfall intensity

Daily rainfall intensity is high in many parts of the country, and the maximum daily amounts estimated for a return period of 10 years are above 100 mm in a high percentage of the Mediterranean coastal and pre-coastal areas of Peninsula, in parts of the Balearic Isles, in others at mid- and high elevations in the Canaries, in many sectors of Galicia and Cantabrian regions, in massifs of the Pyrenees, on the Southwest sides of the Cordillera Central mountains and in sectors of western Andalucia. The central areas of the two Plateaus, however, present more modest intensities, which can be below fifty millimetres for the return period considered. In any case, there is a clear dependence of monthly and yearly precipitation on a very low number of rainy days in much of Spain.

The time of year with the highest risk of torrential rainfall is at the end of summer and in autumn along a coastal and pre-coastal fringe on the eastern, Mediterranean side of the Iberian Peninsula, from Catalonia to eastern Andalucia, covering, inland, the Ebro basin as far as Zaragoza and, to the North, areas of the Pyrenees, spreading eastwards towards the Balearic Isles. In an area covering the eastern Plateau, La Rioja and part of Navarre, it is not uncommon for the maximum daily values to occur in a summer month, whereas in the western area, these occur above all in winter.

The records of daily rainfall in Spain confirm the existence of registers of over 500 mm, almost always in autumn. This amount in one day, even if it is distributed throughout the 24 hours, implies considerable hourly intensities. On one occasion, it may have exceeded 800 mm, November 3rd 1987 in Oliva (Valencia), with 817 mm., although some doubt is cast upon this datum at present, as it may have been the total accumulation of this day and the preceding one. The area of greatest daily rainfall intensity in Spain is the one comprising the regions of Safor, in southern Valencia, and the neighbouring Marina Alta, in northern Alicante. For a return period of 10 years, in certain parts of this region, 250 mm could be expected to be reached or surpassed. Likewise, in some mountain ranges (Grazalema, Cádiz; de Gata, Cáceres) the estimated values are very high.

The percentage contribution of the rainiest days to the annual totals is considerable on the eastern coast of the Iberian Peninsula: 25% of the days with the biggest amounts constitute over 70% of the annual total (Figure 1.6).

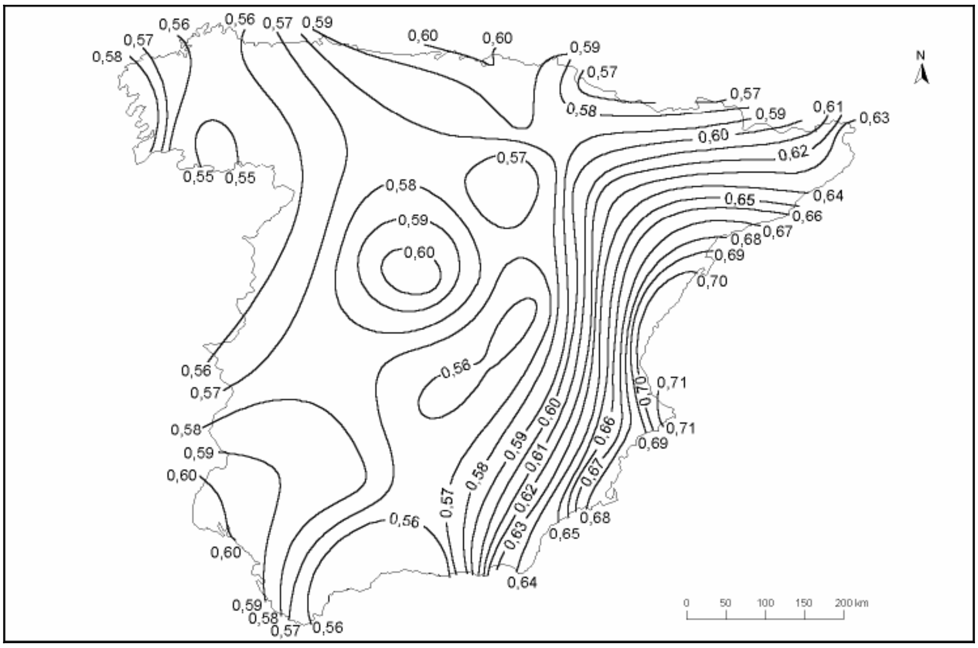

Fig. 1.6. *Index of daily rainfall concentration – the value 0.61 corresponds, approximately, to 70% of the annual total by 25% of the rainiest days- (Martín-Vide 2004).*

In a large part of the fringe closest to the Mediterranean sea, as well as in parts of the mountains, the rainfall intensities over short periods of time (hours or minutes) can reach very high values, typical of certain humid tropical climates, but without reaching their records. The maximum amounts expected in one hour for a return period of 10 years exceeds 50 mm in large parts of the eastern Mediterranean coastal and pre-coastal areas of the Iberian peninsula and in some of the other aforementioned sectors. Many showers in Catalonia, the Valencia Regional Autonomy, Murcia, the Balearic Isles and regions of Andalucia sometimes exceed intensities of 1 mm/min. These downpours, although they do not tend to last long, often cause flooding or drainage problems. In exceptional cases in some parts of Spain, in the previously mentioned regions, instant intensity peaks of over 5 mm/min. One of the records is held by the Valencia town, Manuel, which registered 119 mm in one hour, on July 1st 1993, and did not fall below an intensity of 4 mm/min during 20 minutes).

1.2.3. Other climatic elements

a) Solar radiation

Spain is subjected to an appreciable amount of solar radiation, with values lower than those recorded in tropical latitudes, in conditions of high pressure, but similar to those observed on the equator. The available series for solar radiation, which is measured in very few places (in 1998, 29 observatories comprised the national radiometry network), enable us to conclude: 1) mean daily global solar radiation is lower than 15 MJ/m^2 on the Cantabrian fringe and in much of Galicia, the Pyrenees and the Ebro valley, and it does not reach 12 MJ/m^2 in the more shaded sectors to the north of the Cordillera Cantábrica mountains and on the Basque coast; 2) the southern half of the Peninsula, Ibiza and a large area of the Canary Isles surpass 16 MJ/m^2; 3) in the sectors of the Andalucia coast, as well as in parts of the Canaries, over 18 MJ/m^2 is recorded. The monthly maximums of daily global solar radiation are reached in June and July, with over 20 MJ/m^2, except on the Cantabrian fringe, and up to more than 25 MJ/m^2 in the southern half of the Peninsula, Ibiza and sectors of the Canary Isles. The minimums are concentrated in December, followed by January, with values of less than 10 MJ/m^2, except in parts of the Andalucia coast and in the Canaries, with values of below 5 MJ/m^2 in Galicia, the Cantabrian regions, the Pyrenees and part of the Duero and Ebro basins.

b) Insolation

With the use of insolation records from 88 observatories for the 1961-1990 international period, it has been established that the extreme values occur in Izaña, with 3,448 hours of sunlight per year, in the clear atmosphere, above the layer of clouds, and in Bilbao airport, with 1,525 hours. In Peninsular Spain mean annual insolation also presents great variation, as the values are practically doubled from Bilbao to Cadiz, an observatory that exceeds 3,000 hours of sunlight a year. As a whole, the area with less sunlight in Spain is the Cantabrian fringe, which does not reach 1,750 hours, whereas the a higher amount of sunlight hours occurs on the Costa de la Luz coast, between Cadiz and Huelva, which reaches or slightly surpasses the 3,000-hour threshold.

The 2,000-hour sunshine duration isopleth, a threshold above which solar energy uses can reasonably cover many domestic needs, is practically restricted to Asturias, Cantabria, the Basque country, a non-Atlantic coast stretch of Galicia and some sectors of the Pyrenees. The rest of the country has abundant insolation. The whole southern half of Peninsular Spain, the Balearic Isles, much of the Canary Isles and even large areas in the northern half of the Peninsula, such as the west of the Duero basin, Aragón and southern Catalonia, have over 2,500 hours of sunlight a year. In the Canary Isles, locally and in the northern mid-heights, between around 700 and 1,200 m, relatively low insolation values can be found.

c) Cloudiness

Based on the data on insolation and on the number of days when the sky was clear, or with cloud cover, from 88 Spanish observatories for the 1961-1990 period, the mean annual number of clear days is between only 25.8 in the Vitoria aerodrome and 176.2 in Izaña. In Peninsular Spain there is also much contrast, an example of which is the aforementioned maximum and the 155.8 days in Cádiz, which is six times greater than the first value. The area with the lowest number of clear days, less than 40, is made up of Asturias, Cantabria, the Basque Country and inland Galicia. To the contrary, the area with the highest number of clear days consists of the Guadalquivir valley and the coast of Huelva and the Atlantic coast of Cadiz, as well as places like the Canary Isles, with over 120 days.

The mean annual number of days with cloud cover is between only 13.4 in El Hierro airport and 170.1 and 169.9, in San Sebastián and in Vitoria aerodrome, respectively. In Peninsular Spain there are also sharply contrasting figures. In Cadiz only 53.3 days are registered, less than one third of those in the aforementioned Basque capitals. In the Balearic isles, the airports of Palma de Mallorca and of Ibiza do not reach fifty days. The map showing the number of cloudy days indicates less than 60 days for the Mediterranean coast, from Valencia to Malaga, the south of Majorca, Ibiza, certain parts of the Northeast of Catalonia, the Atlantic coast of Cadiz, Lanzarote, Fuerteventura and the south of the remaining Canary Islands, and high levels for this archipelago. On the other hand, there are over 120 cloudy days in Galicia, except for the Rías Bajas, Asturias, Cantabria, the Basque Country, the Upper Ebro as far as Logroño, northern Castilla y León, part of the Ibérica, Central and Pyrenees mountain ranges and humid parts of the Canary Isles.

d) Air humidity

The values of mean annual relative humidity for the 1961-1990 period for 90 main observatories range from 88 % at Monte Hacho in Ceuta, exposed to the humid air circulating around the Straits of Gibraltar, to 49 % in Izaña, at 2,367 m, immersed in the very dry air covering the trade winds thermal inversion. On the same island of Tenerife and on other mountainous ones of the Canaries, at altitudes lower than that of the aforementioned observatory, the characteristic and persistent sea of clouds gives rise to very high values. Besides the places mentioned, the mean annual values of relative humidity exceed 70% in Galicia, Asturias, Cantabria, the Basque Country, the Pyrenees, the northern third of Castilla y León, the Balearic Isles, the Northeast of Catalonia, the Mar Menor sea, the coast of Cadiz, Ceuta, Melilla and mid-heights and coastal points of the Canaries. In Galicia and the regions of Cantabria, they approach 80%. In short, it is northern Spain and the coasts the areas that present the highest relative humidity; to the contrary, the places furthest away from the sea, Madrid and the surrounding areas, with the lowest annual average.

With regard to the annual relative humidity regime, the following patterns can be established: 1) mean monthly values present variation inland of the Iberian Peninsula, with a winter maximum (75-80%) and a summer minimum (40-50%); 2) annual variation is, to the contrary, low or very low on the coasts and islands (less than 15%); 3) in some coastal observatories in northern Spain, the maximums occur in summer and the minimums in winter. Indeed, in inland Spain, the maximum values in December, January or another winter month, exceed 75 % and in many places, 80 %, whereas in July and August, it is not unusual for them to register below 50 and even 40%. The three-month summer period is the one with the highest relative humidity on the northern coasts of Galicia, Asturias and Cantabria, although it differs little from the other stations.

e) Atmospheric pressure

In much of Spain, atmospheric pressure presents its maximum in winter, almost always in January, and the lowest values in spring, above all in April and in summer, apparently the opposite pattern of what is to be expected. In any case, there are observatories in the northern Plateau, which, with small differences in relation to the winter months, present the maximum value in a summer month. The general seasonal behaviour is due to the predominance of low relative pressures in the inland areas of the Peninsula in summer, resulting from the intense heating of the air, with the consequent drop in atmospheric pressure (1,015-1,017 hPa), whereas on the Cantabrian fringe, there is a belt of high pressure (1,020 hPa) associated with the Azores anticyclone, prolonged in ridge-form towards northern Spain; and to the predominance in winter of high thermal pressures inland (1,020-1,022 hPa) and to a cyclonic area in Galicia, with frequent frontal depressions and cold fronts.

f) Winds

The peninsular nature of much of Spain, the complex orography and the insularity of the rest of the territory favour regional and local winds that become climatically significant elements in the areas they affect. Among the regional winds, we can highlight the Northwest wind, North wind, East wind, West wind and Southwest wind. The Trade Winds are typical of the Canary Isles. Apart from these, the regime of sea breezes characterises the atmosphere of the coasts during the hot half of the year and on other stable days.

The lowest values of total wind speed were recorded in some observatories in the southern Plateau, as well as in certain regions protected from the wind (Bierzo, valleys in Orense, plains of Álava, inland Catalonia), whereas the highest one, for the 1961-1990 period, is in Tarifa, followed by two mountain observatories, Izaña and Turó de l'Home (Montseny, Barcelona). Mountain tops are windier than depressions; certain capes and coastal sectors present high total wind speeds.

With regard to maximum gusts, in the aforementioned period the maximum recorded was in Izaña 200 km/h, and the vast majority of Spain's observatories have, on occasions, surpassed speeds of 100 km/h. Whereas total wind speed does not show any general pattern in its temporal distribution throughout the year, maximum gusts generally occur from October to March. On combining high total wind speed with maximum gusts, the windiest areas of the country are located in the vicinity of the Gibraltar Straits, some capes of La Coruña, the coast of Guipuzcoa, northern Navarre, some buttes in the Ebro valley, the north and south coasts of Catalonia, the trade wind windwards in the Canary Isles and the summits and mountain passes of the main mountain ranges.

1.2.4. Climatic regionalisation

The wide range of values of the climatic elements and their complex spatial distribution hinder the establishment of a clear climatic regionalisation in Spain, which will always have numerous subtypes (Linés 1970; Font Tullot, 2000; Capel Molina 2000; Martín Vide and Olcina 2001) (Table 1.2).

1.2.5. Recent climate tendencies

It is very difficult to make a global and comparative synthesis of the results obtained from the different analyses and studies of the recent tendencies of climatic variables in Spain. The reason fundamentally lies in the use of different observation periods, the variety of the methods used in the statistical treatment of the data, the different spatial cover and the complexity of the territory itself. Even so, there is no doubt about the generalised temperature rise in Spain during the last quarter of a century, whereas rainfall has shown no clearly defined tendencies.

Table 1.2. *Climatic regionalisation of Spain (Martín Vide and Olcina 2001)*

Type	*Subtypes*	*Variety*	*P (mm)*	*Seas. Rainfall Reg.*	*T (ºC)*	*ΔT (ºC)*	*Other charact.*
OCEÁNIC	ATLANTIC	Galicia	1000-2500	Winter max and summ. Min.	11-15	8,5-12	Abundant Cloudiness and High Environmental Humidity
		Asturias and Cantabria	900-1500		12-14	10-11	
		Basque coast	1100-2000		12-14	10-12	
	MOUNTAIN	-	1000-2500	-	<12	-	
MEDITERRANEANO	SUB-MEDI-TERRANEAN	-	700-900		11-14	14,5-16	-
	CONTINENTAL	Northern Plateau	350-550	Wint. Or spring and summ. Min.	10-12,5	16-18	Frosts freq.in wint.
		Southern Plateau	350-550		12-15	18-20,5	High summ. Max. Temp
		Ebro Valley	300-550	Equinoctial maximums	13-15	18-20	Dry NW wind
	EAST FRINGE	Catalonia	550-750	Autumn max. And summer min.	14-17	14-17	Torrential rainfall in autumn
		Valencia	400-850		15,5-17,5	13,5-16,5	
		Baleric Isles	400-800		16-18	13,5-15,5	
	SOUTHERN	Coastal	400-750	Winter max. And summ. Min.	17-18,5	10-13,5	Frost exception
		Guadalquivir Valley	550-650		17-18,5	15-18,5	Very high summ. Max. Temp.
		Extremadura	450-600		16-16,5	16,5-18	High summ. Max. Temp
	ÁRID OR FROM SOUTHEAST	-	150-350	Summ. Min.	14,5-18,5	13,5-17,5	Extrema aridez
	MOUNTAIN	-	600-2000	-	<14	-	-
SUBTROP. / TROPICAL (Canaries)	COASTAL	-	75-350	Winter ma. And summ. Min	18-21	5-7,5	Trade winds in N and extreme aridity in S
	SEA OF CLOUDS	-	500-1000		13-16	6-8	High environmental humidity
	IN HEIGHT	-	450-700		<12	12-14	Very dry air

P, mean annual rainfall (mm); Seas. Rainfall Reg., seasonal rainfall regime; T, mean annual temperature (ºC); ΔT, annual mean temperature range (ºC).

a) Temperature increase

The increase in the mean annual temperature of the earth's surface during the last century, and more specifically, following the end of the 70's of the XX century, it was confirmed by the analyses based on regional series obtained through the interpolation of the observations covering different regions of Spain and of the longest individual series existing in the country (Raso 1997). Although a long-term understanding of air temperature in Spain is still far from being complete at a detailed spatial scale, some recent studies deal with the country as a whole or with certain parts of the Peninsula. Thus, in a preliminary analysis for the 1864-1999 period of homogenised regional series of monthly averages of maximum and minimum and mean temperatures from 98 observatories covering the whole of Spain, a statistically significant increase has been established in the three variables, both annually and seasonally, more obvious in winter than in summer (Brunet *et al.* 2001a). With an explicit correction of the urban effect, a research project dealing with 45 Spanish observatories, 27 of these with series starting in 1869, has reached the following conclusion: 1) maximum temperatures have risen significantly since the 70's of the XX century, except in Galicia, by 0.6ºC/decade, as a mean value, although with appreciable regional variations; 2) minimum temperatures have undergone a similar increase; and 3) warming has been detected mainly in winter (Staudt 2004). As a whole, it is the North and Northwest of the Peninsula the area with the lowest variations (Oñate and Pou 1996). Although on the Peninsula, the year in which the recent global warming started can be established somewhat before the one often used at global scale – 1976- the tendencies of the series of mean annual temperature in Spain analysed in the *European Climate Assessment (ECA)* from this year (Badajoz-Talavera, Salamanca, San Sebastián, Roquetes-Tortosa and Valencia) show, like the rest of the European ones, an increase of at least 0,3ºC/decade, in the 1976-1999 period (Klein Tank *et al.* 2002). This contrasts with negative tendencies in the previous thirty-year period 1946-1975. In Badajoz, Tortosa and Valencia there is a significant tendency throughout the 1946-1999 period, both in the number of hot days and summer days (positive) and in the number of cold days (negative).

Different studies of Spanish regions coincide in one essential fact: After the decade of the 70s, warming has become visible and significant. Thus, several studies with data from 9 stations in the northern Plateau have revealed a growing significant tendency of mean annual minimum temperatures of 0.051ºC/year, in the 1972-1994 period, which did not exist in the longer temporal interval 1945-1994 (Labajo *et al.* 1998; Labajo and Piorno 2001), and of mean annual maximums (Labajo and Piorno 1998). The rise in minimum and mean temperatures, but not in maximums, had already been established in 5 cities of the same regions (including Madrid), with series which in two cases started in 1869 and finished in 1992 (Esteban-Parra *et al.* 1995).

Analysis of the variations and tendencies of the maximum and minimum mean annual temperatures in the Southern Plateau in the 1909-1996 period, following the homogenisation with the use of the SNHT test of the series from 21 stations, and the subsequent design of a regional series, showed, as the most relevant results: 1) Maximum annual temperatures have shown a significant increase, calculated at 0.71ºC during the aforementioned period, whereas the tendency of the minimums, also positive, lacks any statistical significance; and 2) The temporal evolution shows phases parallel to the planetary ones, and that of the final interval 1972/73-1996, is characterised by a significant increase, both in maximum and minimum temperatures, of 1.62ºC and 1.49ºC, respectively (Galán *et al.* 2001). Similar results were obtained from 7 main observatories in the region (Cañada *et al.* 2001).

For Aragón, Navarre and La Rioja, analysis of the homogenised series of mean seasonal values of maximum and minimum daily temperatures in 15 observatories during the 1921-1997 and 1938-1997 periods, respectively, provided the following results: 1) Since the beginning of the seventies, generalised warming has been recorded, which is not seasonally homogeneous, given that it is not detected in autumn, but which is particularly clear in relation to maximum springtime temperatures, 0.143ºC/year (1975-1997), and summer ones, 0.096ºC/year (1973-1996); 2) in spring, the increase in daily temperature range is significant; and 3) with the exception of autumn, there has been a general decrease in variability since half way through the 70s, so that the anomalies observed do not exceed those previously observed (Abaurrea *et al*. 2001).

Analysis of the 23 stations in the Segura basin for the 1940-1997 period, coincide with regard to the significance of their growing tendency since the 70s. Likewise, spring is the season that presents most warming, 0.123ºC/year for the maximums (1970-1997). The greatest increases in maximums occur in the mountain areas, whereas it is the lowlands that have shown the biggest increase in minimums (Horcas *et al.*,2001).

Other regional series of maximum, minimum and mean temperatures at seasonal and annual resolution for Catalonia, based on data from 23 stations, preferably located in non-urban sectors, and with the verifications of homogeneity by the SNHT test, have allowed for the establishment of temporal patterns in the region for a period greater than one century (1869-1998). Three phases have been distinguished: a thermal increase between 1869 and 1949, of 0.01ºC/year; a brief cold spell, although also significant, of -0.03ºC/year, from half way through the century to the middle of the 70s; and the notable temperature rise since then until the end of the period, by 0.07ºC/year (Brunet *et al.* 2001b) (Figure 1.7). For the whole period, the increase is of 0.89ºC, winter, with 1.78ºC, being the season subjected to the highest level of warming, and summer, to the smallest increase, 0.59ºC. The series of annual and seasonal mean maximum and minimum temperatures confirm similar patterns, with a slightly bigger increase in the former ones (0.96ºC) than in the latter ones (0.82ºC) (Brunet *et al.* 2001c). For the Fabra observatory (Barcelona), respective analyses of daily maximum and minimum daily temperatures have confirmed their different behaviour patterns and the general upward tendency (Serra *et al.* 2001).

In a study based on data from 23 observatories in the Valencia Regional Autonomy and in Murcia, for the common period 1940-1996, a notable difference was noted in the evolution of the daily temperature range of the urban and rural observatories, which led to the conclusion that much of the warming observed in the thermal series of the former was due to urban influence (Quereda and Montón 1999), and very recently, an attempt has been made to evaluate this effect with the use of teledetection (Quereda *et al.* 2004). Furthermore, a change can be seen in the day-to-day variability of the series of daily temperatures in Cádiz-San Fernando over a period lasting from the first quarter of the XIX century to the last decade of the XX century (Moberg *et al.* 2000).

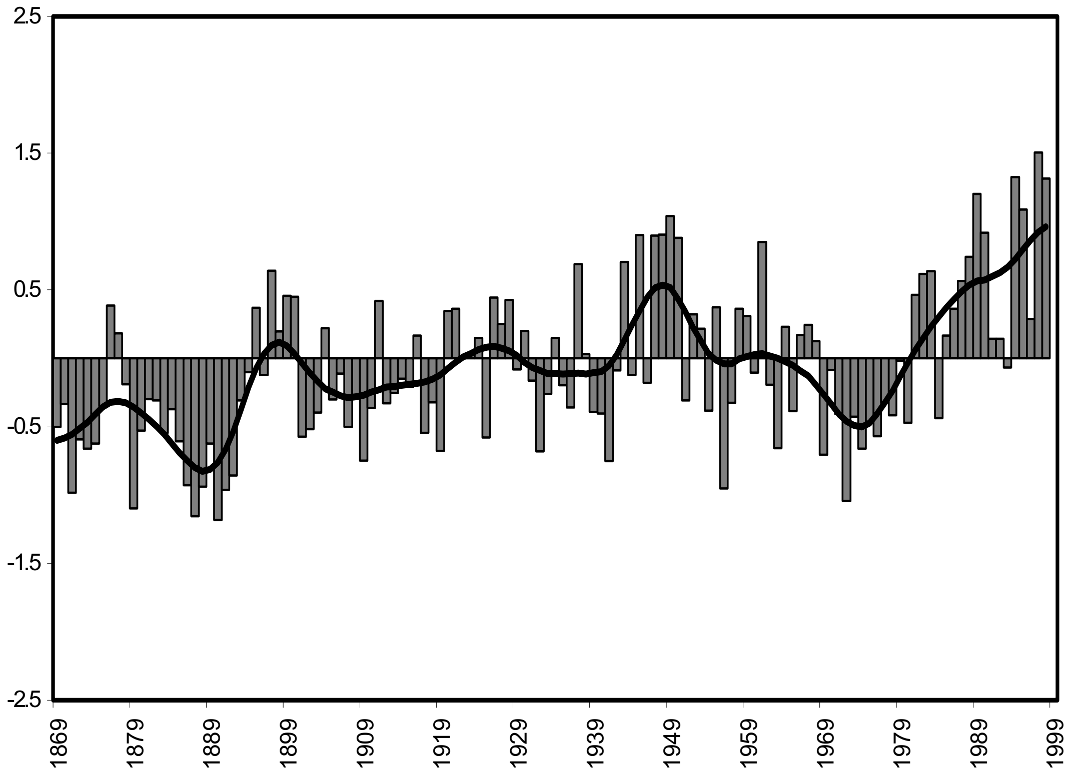

Fig. 1.7. *Annual mean temperature anomalies, relative to the average for 1961-1990, in NE Spain (ºC)(1869-1998) –smooth curve using a 13-point Gaussian filter (Modified from Brunet et al. 2001b).*

b) Rainfall undefined trends

The tendency to decrease of the rainfall totals in subtropical latitudes mentioned in the third IPCC report (IPCC 2001) cannot be easily verified in the case of Spain, given the complexity of the spatial distribution of rainfall, not only with regard to amount, but also to its seasonal distribution and temporal concentration, which requires the use of a considerable number of climatic series, rarely available with the necessary longitude. There is no exhaustive study allowing the whole country to be covered at detailed spatial resolution. Furthermore, the high temporal variability in much of Spain, inherent to its Mediterranean condition, requires long series, preferably centennial ones. The 10 Spanish mean annual rainfall series analysed in the *ECA* (Badajoz-Talavera, Madrid, Málaga-airport, Navacerrada, Salamanca, San Sebastián, Torrevieja, Roquetes-Tortosa, Valencia and Zaragoza-airport) for the 1946-1999 period, unlike a certain number of European series, do not show any increase in the totals, in accordance with a foreseeable general increase in global rainfall. In the case of the same Spanish observatories, no significant tendency was observed, either, in the annual number of rainy days (≥1mm). With regard to the evolution of the amounts of rainfall above determined thresholds, and the percentage contribution of the rainiest days to the annual total, which could reflect variations in rainfall intensity, only Madrid shows a negative tendency in the first case, and together with Tortosa, in the second one (Klein Tank *et al.* 2002).

In the secular context, the longest annual rainfall series for the Iberian Peninsula, starting in the XIX century (Gibraltar, at the end of the XVIII, 1791), show no significant tendencies, with the exception of some southern ones (Gibraltar, San Fernando) with a statistically significant downward trend (Wheeler and Martín-Vide 1992; Quereda and Montón 1997). Research into the 53 longest annual rainfall series available up to 1990, including some from the Balearic Isles and the Canary Isles, produced a map with a broad central area, from Extremadura to Valencia Regional Autonomy and Catalonia, as well as the Balearic Isles and the Canary Isles, with no defined tendency; the North and Northwest of the Peninsula, with a certain upward trend; and the South and Southeast of the Peninsula, with a tendency to decrease (Milián 1996). In another analysis of data from 40 observatories on the Peninsula and the Balearic Isles, during the 1880-1992 period, differentiated behaviour was detected between the northern Iberian fringe, with an upward tendency, and the inland and Mediterranean side, showing a downward trend (Esteban-Parra *et al.* 1998). In other studies with time duration series somewhat lower than one century (Serrano *et al.* 1999; García *et al.* 2002; Muñoz-Díaz and Rodrigo 2004) or with grid data from the 1900-1996 period (Rocha 1999) no clear annual tendencies were detected, although there does appear to be a consistent decrease in springtime rainfall.

Regionally, a series of annual areal rainfall for the watersheds in the Southeast and East, covering the 1864-2000 period, showed no significant tendency (Chazarra and Almarza 2002). Almost thirty annual series for the Ebro basin, in the 1920-2000 period, which allowed for regionalisaiton according to temporal evolution, showed no monotonous tendencies in any of the areas considered (Abaurrea *et al.* 2002). Nor were they detected in the southern Plateau in 6 observatories (Galán *et al.* 1999). In Catalonia, with data from 121 stations, no significant tendency was detected in the annual rainfall during the last century and a half, although it was in spring, with a decrease of over 25% (Saladíe 2004). Other analysis also dealing with time duration series close to or over one century detect certain rainfall anomalies and some rainy periods, and among other general facts, we can identify the initial period of the series, up to the end of the XIX century or the beginning of the XX century, as rainy, like the 60s and 70s of this last century, whereas, in comparison, at the end of the 70s, a dry period started (Rodríguez *et al.* 1999; Rodrigo *et al.* 2000; Ramos 2001, etc.). In the secular context of the last half millennium, the amount of rainfall, reconstructed with the use of *proxy data*, shows a reduction in the last few decades of the XX century both in the South of the Peninsula (Rodrigo *et al.* 1999), (Figure 1.8) and in the North (Saz 2003).

When the analysis refers to the last third of the XX century, a significant decrease can be seen in the amount of rainfall in certain regions covering Peninsular Spain and the Balearic Isles. This occurs in the 1963-1985 period in the eastern and Pyrenees sectors of the Ebro basin (Abaurrea *et al.* 2002). In some studies, this decrease is particularly due to the reduced winter rainfall and -as we have pointed out previously- spring rainfall also, which is associated with the increase in atmospheric pressure in the western Mediterranean since the 70s of the XX century, in turn partly caused by the reinforcement of the positive mode of the Mediterranean Oscillation (Dünkeloh and Jacobeit 2003) and also by the occurrence of a positive phase of the NAO. In the regions of Spain on the Mediterranean façade, from Andalucia to Catalonia, including the Balearic Isles, the reduction of rainfall in the 1964-1993 period, on comparing its two 15-year sub-periods, occurred in much of Andalucia and Catalonia, in Menorca and the Northwest of Mallorca, whereas the variation is positive in much of the Valencia Regional Autonomy and Murcia, as can be seen from the analyses from 410 weather stations (Romero *et al.* 1998; Guijarro 2002). The downward tendency during the last international period (1961-1990) has been confirmed for southern Spain in other studies (Rodrigo *et al.* 1999). In the Valencia Regional Autonomy almost one hundred rainfall stations confirm the reduction of annual rainfall and an increase in interannual variability during the last international period (1961-1990), although with very notable spatial differences (De Luis *et al.* 2000).

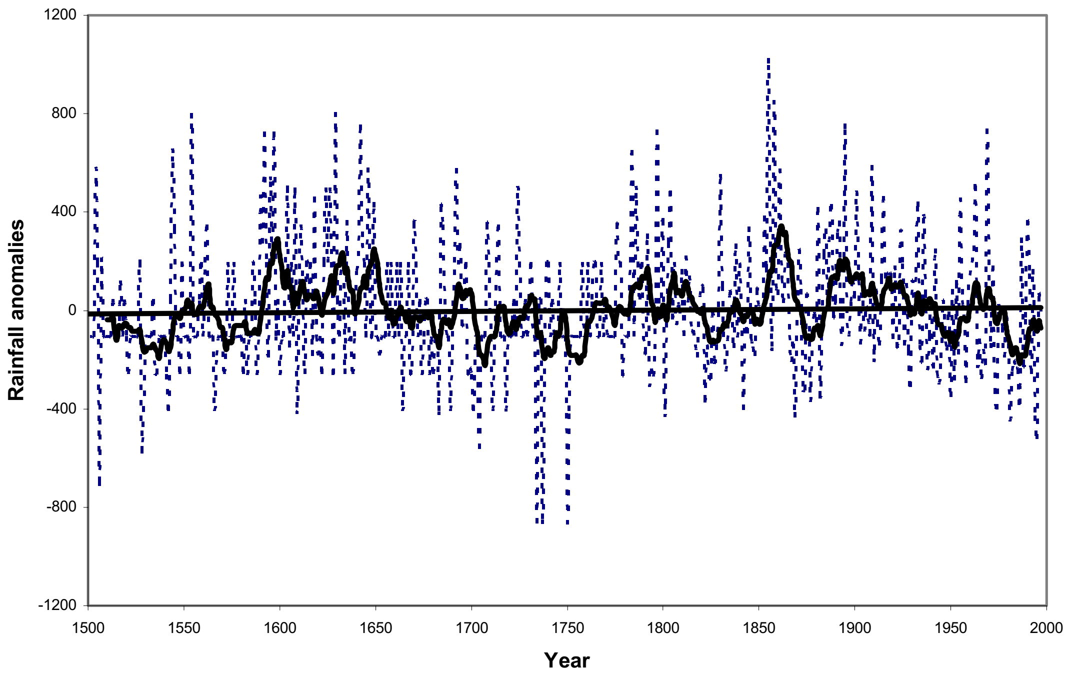

Fig. 1.8. *Annual precipitation anomalies in Andalucia (mm) (1500-2000) –smooth curve using 10-year moving averages (Rodrigo et al. 1999, 2000).*

With regard to interannual rainfall variability, which presents great complexity in Peninsular Spain (Rodríguez-Puebla *et al.* 1998), the hypothesis of an increase has not been clearly confirmed in a secular context. Thus, the anomalies in rainfall during the XX century show similar behaviour to those of the previous four centuries in Andalucia (Rodrigo *et al.* 2000), although there is high variability in the second half of the XX century (Pita *et al.* 1999). In the last few decades, interannual variability has also increased in other regions, and even in the southern Plateau the growing tendency appears to cover the XX century (Galán *et al.* 1999).

The possible changes in the seasonal distribution of rainfall, with ecological and socioeconomic implications, indicate heterogeneous spatial behaviour patterns. An unpublished analysis of data from 55 Iberian meteorological stations for the 1949-2003 period has shown a decrease in winter rainfall in the Cantabirain corniche (Bilbao, 2,22 mm/year) and in spring rainfall in more southern regions (Seville, 1,4 mm/year) (Rodríguez-Puebla, pers. com.), with no tendencies in summer and autumn. A seasonal index applied to over 400 rainfall stations in eastern and southern Spain has shown an increase throughout the 1964-1993 period in Andalucia and inland Catalonia, coinciding with an increase in rainfall in October (Sumner *et al.* 2001). In the Valencia Regional Autonomy there has been a decrease in winter rainfall, and even in autumn, accompanied by greater interannual variability in the last international period (González-Hidalgo *et al.* 2001). An index of intrannual rainfall concentration has shown a growing tendency in San Fernando and Madrid during periods starting half way through the XIX century and ending at the end of the XX century (López 1999).

Temporal rainfall patterns at daily resolution are of great interest in the context of Spanish climates, given the high temporal concentration of rainfall, with the consequent problems related to drainage and erosion. There are very few studies in this respect, however. The analyses published do not allow us to infer an increase in the daily intensity of rainfall, that is to say, a greater influence of the days with big amounts over the total number of days of rainfall. Thus, for the 1958-1997 period, and based on data from 18 observatories on the Iberian Peninsula, in much of the country, except for the Southeast, there has been a tendency towards a lower number of days with big amounts of rainfall (Goodess and Jones 2002). The tendencies of the 10 rainiest days in the Valencia Regional Autonomy are not clear, either, nor of their percentage contribution to annual totals, the former presenting downward trends and the latter upward ones (González-Hidalgo *et al.* 2003). In any case, chronological analysis of the daily rainfall series shows quite different behaviour patterns from one observatory to another (López 2001). In Barcelona an analysis covering the period from 1917 to the end of the XX century detected an increase in the amount accumulated by the days reaching or surpassing the 95% percentil (29.5 mm), in a context of less rainy days (Burgueño *et al.* 2004). In the Canary Isles, a clear decrease in rainfall was detected during the second half of the XX century, fundamentally due to a decrease in the most abundant daily amounts (García-Herrera *et al*. 2003).

1.2.6. Low-frequency variability patterns

The dipole constituted by the Azores anticyclone and the Icelandic low, that composes the North Atlantic Oscillation, has a noteworthy influence on winter rainfall in centre and Southwest of mainland Spain. The correlation between the NAO index and monthly rainfall in the cold months is significant and negative in the area in question, with abundant rainfall, often associated with depressions in the vicinity of the Gulf of Cadiz. To the contrary, in its positive phase, it receives amounts of rainfall that are clearly below normal, given the proximity of the Azores high.

Certain change patterns can be deduced from the growing number of studies relating low-frequency variability patterns with the behaviour of the climatic variables in Spain. Thus, the clear positive tendency of the NAO index since the middle of the 60s (Gámiz-Fortis *et al.* 2002), which has been associated with the aforementioned decrease in rainfall, also seems to involve a growing tendency in relation to atmospheric pressure. An analysis of the evolution of synoptic circulation on the Iberian Peninsula in the XX century has started to show that the subtropical pattern is becoming increasingly frequent, at the expense of the westerlies (Fernández and Rasilla 2001). In any case, the North Atlantic pattern is modulated by other ones, such as the EU2 for drought on the Iberian Peninsula (Vázquez López 1999). The influence of the NAO, and of other teleconnections, such as the SCAN or the EA, showing changes in phase in 1976, affects rainfall variability in Galicia (Taboada *et al.* 2002). However, the decadal oscillations of the NAO, and the tendencies of this, are not clearly seen in the Iberian temperature records, which are much more sensitive to the location of the southern centre of the dipole than to the barometric gradient in the North (Castro-Díez *et al.* 2002). It is precisely the position of the Iberian Peninsula that prevents certain low-frequency variability patterns from clearly becoming manifest, and during winter, temperatures in periods of over 15 years therefore only show hemispheric variability, fundamentally radiative (Pozo-Vázquez 2000).

The duration of insolation is positively correlated with the NAO index in southern Europe, and a positive phase of the aforementioned pattern therefore involves anomalies of the same sign (Pozo-Vázquez *et al*, 2004). A percentage of 50% of the variability in rainfall in the three-month period of spring is accounted for by the NAO and EA patterns (Martín *et al.* 2004), which can explain their downward tendency in some regions of Spain. The dry and rainy periods in the same season are influenced by the AO, the EA/WR and the Southern Oscillation Index, and the springtime reduction during the El Niño episodes can be estimated at 10% (Rodó *et al.* 1997; Rodríguez-Puebla *et al.* 2001; Mariotti *et al.* 2002). The decrease in the number of cyclonic days and in the number of days with a negative anomaly of pressure in the March-April period in the western Mediterranean basin (Laita and Grimalt 1997), as well as the variability observed in temperature (Pozo-Vázquez *et al.* 2001), following ENSO episodes could be related to the greater frequency, intensity and persistence of El Niño for just over the last 20 years. To the contrary, there is no relationship between El Niño and storms over the sea on the coast of Catalonia (Camuffo *et al.* 2000). The clear increase in the number of days with red rain in Elche, in the last few years of the 1949-1994 period, might be the reflection of an increase in meridional circulation (Quereda *et al.* 1996). Baroclinic activity and winter rainfall are clearly interrelated in eastern Cantabrian region (Sáenz *et al.* 2001)

The daily data on different variables from the Roquetes-Tortosa observatory for the 1910-1994 period enable us to conclude that the climate therein has tended to be warmer and drier (Piñol *et al.* 1998). Thus, the increase in mean annual temperature by 0.10ºC/decade has led to an increase in estimated potential annual evapotranspiration of 13mm/decade. As there has been no significant change in rainfall, there has been a growing tendency towards hydric deficit. Furthermore, from June to September in the 1941-1994 period, daily minimum relative humidity fell by 0.8%/decade. All of this has led to a rise in the forest fire risk indices.

1.3. FUTURE CLIMATE

1.3.1. Global climate models

In order to make projections of climate change related to the growing accumulation in the atmosphere of greenhouse gasses (hereinafter GHGs) and of aerosols, resulting from human activity, global climate models are currently used. A climate model consists of a mathematical representation of the processes taking place in the “climate system”, the state of which defines the climate. The climate system is considered to be made up of five components: atmosphere, hydrosphere, cryosphere, lithosphere and biosphere (Peixoto and Oort 1992). Between them, there are huge exchanges of matter, heat and momentum and incessant interactions through a multitude of physical, chemical and biological processes, all of which makes the earth’s climate system tremendously complex. Global climate models are currently the best tool available for the study of the processes constituting the state of the climate. This is why they are indispensable for establishing the response of the climate to disturbances caused by human activity. Consequently, the capacity of the models to project the future evolution of the climate basically depends on an understanding of the processes governing the climate system.

At present, most global climate models include a certain level of representation of the five components of the climate system, of the processes taking place in each one of them, and of those determining the mutual exchanges. Current climate models explicitly include both the atmosphere and ocean processes along with their major interactions. This is because the ocean plays a crucial role in the Earth’s climate and its variability. Although until less than a decade ago, its function was underestimated, it is now believed to be as important as the atmosphere. Thus, understanding climate and predicting its evolution involves considering the ocean too.

The models in which the atmosphere and the ocean jointly interact are generally known by the AOGCM (Atmosphere-Ocean General Circulation Model), which will be used hereinafter to refer to them.

The AOGCM are based on the resolution of a set of mathematical equations that express the laws of Physics governing the dynamics of the atmosphere and the ocean. It is a complex, non-linear set of differential equations that have no analytical solution. Thus, they must be solved in an approximate manner, by applying numerical techniques, which require a division of the space occupied by the atmosphere and by the ocean into three-dimensional cells. In each one of these, values of the variables are assigned that characterise the state of the atmosphere and of the ocean, such as temperature, motion, density, etc. This allocation is based on direct or indirect observations of these variables at global scale in a determined initial instant. In order to derive the temporal evolutions of the variables in each cell of the model grids, the initial values are used to solve the equations. These evolutions are obtained in discrete temporal intervals (time steps), the duration of which must be in accordance with the size of the cells. The smaller this size, the smaller the time step. The spatial resolution of the atmospheric part of the current AOGCM ranges from 2º to 10º latitude and longitude horizontally, and vertically, from 10 to 30 layers are considered between the surface and the upper limit of the atmosphere, each one with variable thicknesses, whereas the horizontal and vertical resolutions of the oceanic part are usually similar or somewhat higher than the atmospheric ones.

Furthermore, the discretisation needed in the numerical techniques in order to solve the differential equations set implies that they cannot be used to solve those atmospheric or oceanic processes with spatial or time scales lower than the resolution of the model, for example, individual clouds in the atmospheric models or intermediate scale eddies in the ocean models. This is why the effect should be calculated using a parametric representation according to values of the basic variables solved by the model. This procedure is called parametrisation.

The AOGCM models are combined with empirical or semi-empirical mathematical representations of other components of the climatic system, such as the cryosphere, soil surface or plant cover. The current, more complete models also include representations of the carbon cycle, such as exchanges between the atmosphere, the biosphere and the oceans, and of processes affecting the aerosols in the atmosphere, such as chemical reactions, aggregations, deposition and effects on the formation of clouds (see chapters 3 to 6 of the IPCC report 2001).

We previously pointed out that the set of differential equations of an AOGCM is solved in discrete temporal intervals or “steps”. This means that in each one of them, the model must solve all the equations in order to calculate the updated vales of the variables in all the cells of the three-dimensional grid encompassing the planet. This involves having to do millions of mathematical operations in each time step (from 30 to 60 minutes, depending on the models), until the whole integration period has been completed, which is usually extended to hundreds of years. This obviously requires the use of the most powerful computers available.

There are currently only a couple of dozen AOGCM models, developed in climate centres and universities thanks to a huge effort invested in scientific research. A clear example of this is that in the first report by the Intergovernmental Panel on Climate Change (IPCC), drawn up in the year 1990, results were presented from only two AOGCM, whereas in the latest one (IPCC 2001) almost a score of these more perfected models were mentioned.

The AOGCM models used to quantify the future response of the climate to disturbances caused by human activity must previously be evaluated. The reliability test for an AOGCM, with regard to reproducing the main processes of the climate system, is based on a systematic comparison between results of simulations with current climate conditions and the climatological data observed. Simulations of the present climate with AOGCMs take into account the evolution of values observed of atmospheric concentrations of GHGs. The models can also be evaluated considering palaeoclimatic conditions, for example, the last glacial period. Once its quality has been satisfactorily evaluated, the model is used to make simulations of the temporal evolution of climate change.

In this type of evaluations, it has been seen that most of the current AOGCMs have been greatly improved in the last ten years. This is attributed to several causes, among which we can highlight a better knowledge of the characteristics of the oceans and of the processes of exchange with the atmosphere, consideration of the processes affecting the sulphate aerosols in the atmosphere, and of the increased spatial resolution of the models (smaller cell size) permited by the tremendous increase in computing power. Indeed, the simulations generally provide a very acceptable reproduction of the evolution of global temperature over the last 150 years. So much so, that the tests carried out with different evolutions of GHGs have allowed for a discrimination of the contribution of human activity to climate change, with an acceptable degree of reliability (Stott *et al*. 2001).

The AOGCM models, however, still provide some uncertain results, to a great extent associated with deficiencies in the parametrisations of some physical processes that are determinant for the climate, such as those related to the formation of clouds and precipitation, the thermohaline circulation of the oceans, the dynamics of sea ice or biogeochemical exchanges in the climate system, among others (for more details, see chapter 14 of the report - IPCC 2001). Apart from these deficiencies, there is the problem that the spatial resolution of the AOGCMs is still too low to reproduce orographic and coastal details, which in many parts of the planet, are decisive with regard to determining climate at regional scale. An illustrative example of this is the case of the Iberian Peninsula, which will be subsequently dealt with.

1.3.2. Climate simulations with global models

In order to simulate the future evolution of the Earth's climate, the AOGCM models must be transitorily forced with evolutions of the levels of GHGs and aerosols accumulated in the atmosphere according to how emissions caused by human activity are expected to change. That is to say, to design what are known as "emission scenarios". This is done considering different suppositions regarding future demographic and socioeconomic development in the world. The emission scenarios currently used to make projections with climate models throughout the XXI century are known as SRES (Special Report on Emission Scenarios). They constitute a set of emission scenarios created by a group of world experts from the IPCC (Nakicenovic *et al*. 2000), taking into account coherent hypotheses of the future evolution of world population growth, energy demand, efficient use of this or global economic growth, among other considerations.

For each of these scenarios, we made a quantification of future anthropogenic emission of GHGs and sulphur compounds (IPCC 2001). By way of an illustration, Figure 1.9 shows the evolutions of CO_2 and SO_2 emissions corresponding to the six scenarios that have been used up to now to make climate projections with the AOGCM models. In the same figure are included the evolutions of global CO_2 concentration for each of the emission scenarios considered, according to the result of the application of the carbon balance models (for example, Cramer and Field 1999). From these six scenarios, the so-called A2 and B2 are the two most used by the AOGCM models. From a purely technical point of view, however, they should all be considered as equally probable. In this sense, it should be pointed out that none of them correspond exactly to the emission objectives established by the Kyoto protocol.

Of the AOGCM mentioned in the third IPCC report (2001), six have been used to make detailed simulations considering different evolutions of levels of GHGs and sulphate aerosols throughout the XX and XXI centuries (table 1.31). The IPCC's Data Distribution Centre (DDC) avails of the set of results derived from different simulations made with these six AOGCM. These simulations generally cover a period of 240 years, from 1860 to 2100. In the first 130 years (1860-2000) the concentrations of GHGs observed in the atmosphere are considered, together with estimates of sulphate aerosols, and after this year, different emission scenarios are taken into account. Table 1.3 provides details of the SRES emission scenarios considered in the simulations made by each AOGCM, the results of which can be obtained from the DDC-IPCC. Most of these data correspond to the monthly values of the variables most used in studies of the impact of surface climate change (temperature, precipitation, pressure, etc.), corresponding to each one of the cells of the mesh of the model covering the whole of the Earth's atmosphere.

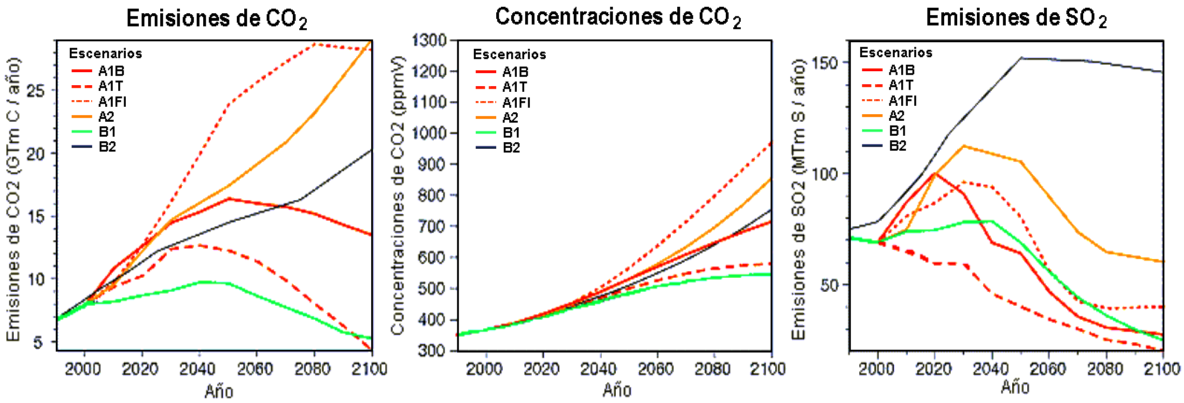

Fig. 1.9. Evolutions of global CO_2 and SO_2 emissions into the atmosphere resulting from human activities, and of global CO_2 concentrations that would result from these emissions, according to different SRES scenarios. Taken from IPCC (2001)

***Table 1.3.** Characteristics of the AOGCM, ans SRES emission scenarios simulated by these, the results of which can be obtained from the DDC-IPCC: http://ipcc-ddc.cru.uea.ac.uk/dkrz/dkrz_index.html. The horizontal size of the atmospheric and oceanic cells is expressed in degrees of latitude-longitude, and the number of levels on the vertical appears in brackets).*

NAME OF THE MODEL	CENTRE (COUNTRY)	ATMOSPHERIC RESOLUTION	OCEANIC RESOLUTION	SIMULATED SRES SCENARIOS
CCSR/NIES 2	CCSR/NIES (Japan)	5.6 × 5.6 (20)	2.8 × 2.8 (17)	A1,A1FI,A1T,A2,B1,B2
CGCM 1,2	CCC (Canada)	3.7 × 3.7 (10)	1.8 × 1.8 (29)	A2,B2
CSIRO-Mk2	CSIRO (Australia)	5.6 × 3.2 (9)	5.6 × 3.2 (21)	A1,A2,B1,B2
ECHAM4/OPYC3	MPIM (Germany)	2.8 × 2.8 (18)	2.8 × 2.8 (11)	A2,B2
GFDL R30 c	GFDL (USA)	2.25 × 3.75 (14)	1.875 × 2.25 (18)	A2,B2
HadCM3	UKMO (United Kingdom)	2.5 × 3.75 (19)	1.25 × 1.25 (20)	A1,A1FI,A2,B1,B2

The evaluation of the results obtained at global scale in the set of simulations corresponding to the XX century (IPCC 2001), shows that the quality of none of them is clearly higher than any of the others. Indeed, Lambert and Boer (2001) showed, for example, that the distributions of temperature, pressure and rainfall resulting from a mean value of an ensemble of several AOGCM, are generally more similar to the ones observed than those obtained from any of them individually. In spite of the differences between the results obtained by each of the models, comparison with observations enables us to feel reasonably sure that the AOGCMs are suitable for simulating future climate changes, notably reducing the uncertainties involved in climatic projections (IPCC 2001).

Although it has been pointed out before that none of the SRES scenarios can be presumed to be more probable than any of the others, the climate projections that are now presented correspond to groups A2 and B2, due to being the two considered by the highest number of AOGCMs. This enables us to perceive the future response of the future climate according to the evolutions of anthropogenic emissions. Furthermore, only the results of the models included in DDC-IPCC are presented. In spite of the fact that these AOGCM have been evaluated with current climatic data, and that it was ensured that all of them reasonably reproduced the main features of global climate, each simulation presents differences in relation to the others. Thus, for example, Figure 1.10 shows projections of mean annual changes in global air surface temperature, obtained with different AOGCMs, for the two emission scenarios considered. Therein it can be seen that, in some cases, the differences between models exceed the individual interval of the projected climatic changes. But, it must be said that, as the IPCC points out, these differences do not invalidate the results, but rather provide valuable information, because they facilitate an objective evaluation of the reliability involved in each individual projection. Indeed, analysis of the set of results obtained with different models enable us to identify the features of the projected global climate change common to all the simulations, which can be considered to be most reliable. Thus, for instance, as all the models coincide in that the temperature increase is greater in scenario A2 than in B2, we can be quite sure that future global warming will be determined, to a great extent, by the rhythm of the increase in anthropogenetic emissions of GHGs and aerosols.

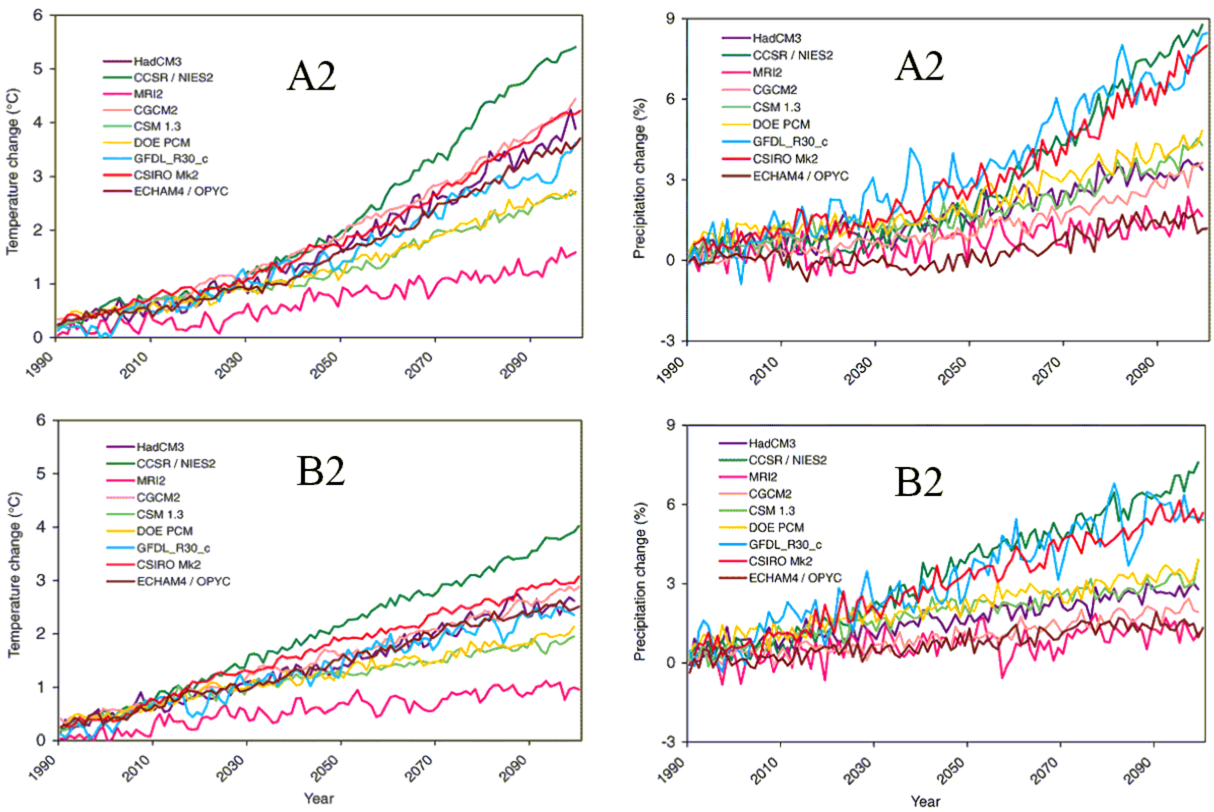

Fig. 1.10. *Evolutions of mean global changes in temperature (above) and in precipitation (below) in relation to 1990 values, simulated by different AOGCMs considering SRES-A2 (left) and SRES-B2 (right) emission scenarios. Figure taken from IPCC (2001)*

1.3.3. Future climate projections in Spain made with global models

Because of the differences between models, it was considered most convenient first to show the results of the spatial distribution on the Iberian Peninsula of projected changes in surface temperature and rainfall throughout this century obtained with a determined AOGCM. The results of simulations with several AOGCM in an inland area of the Peninsula are afterward presented, in order to make a simple comparison and to compose rests of the set.

The AOGCM chosen for the first analysis is the HadCM3, developed in the Hadley Centre for Climate Prediction and Research (United Kingdom). As has already been mentioned, this choice must not be seen as indicative of the superiority of this AOGCM over any other one, although it is true that the results of the simulations with the HadCM3 model in relation to climate change (1960-90) on the Iberian Peninsula generally present an acceptable fit with the observations. But the main reason for this choice was that a regionalisation method was applied to this model output in order to obtain greater detail of the changes projected for the last third of the century on the Iberian Peninsula, as is presented in the following section.

The HadCM3 model is an improved version of the previous HadCM2, in which, apart from increasing resolution, it is not necessary to make an artificial adjustment in the heat flux and freshwater flow in order to establish a correspondence with the behaviour observed. In Gordon *et al*. (2000) and Pope *et al*. (2000) a complete description of the model can be found. A brief explanation, however, of the main characteristics of this AOGCM is included.

The atmospheric sub-model has a horizontal resolution of 2.5º latitude and 3.75º longitude covering the whole planet. This means that the cells have horizontal dimensions of approximately 300 x 300 km in average latitudes. Vertically, the atmosphere is divided into 19 levels, with variable spacing between them. The model includes sophisticated parametrisations of solar and terrestrial radiation exchanges, explicitly including the effects of GHGs and aerosols, of the atmosphere-surface-vegetation exchanges and of cloud and precipitation formations. In this sub-model, the emission, transport and deposition of sulphur compounds is also interactively simulated.

The ocean sub-model has a horizontal resolution of 1.25º latitude and longitude and considers 20 levels vertically. A series of improvements has been included in this sub-model, among which we can highlight the one that permits the mixture of water from the Mediterranean with the Atlantic through the Straits of Gibraltar, in spite of the fact that the large size of the cells prevents this from being explicitly resolved by the model, as well as a better parametrisation of processes of sea ice and snow accumulation.

In the experiments with the HadCM3 model, the atmosphere and ice cover are initiated with available values and the ocean is considered to be at rest. With these initial values, the model is applied over a period of 1,000 years, with levels of GHGs and aerosols corresponding to pre-industrial times. Such a long period is needed in order for a suitable adjustment between atmosphere and oceans to be made. At the end of this period, the state of the simulated climate represents the conditions previous to the year 1860. From that year to the present, the model was forced with growing levels of GHGs and aerosols, deduced from the available observations. In the future years, the evolutions of GHGs and aerosols correspond to the diverse SRES emission scenarios. The results obtained with the model in the 1960-1990 period are used to appraise their degree of correspondence with present climatology. Lastly, the projections of climate change with the model are obtained from the differences between the climate simulated for the 1960-1990 interval and the one resulting from any 30-year period throughout this century. In the experiments with the other AOGCMs a similar sequence is followed. We now present climate change scenarios for three periods: 2010-2040 2040-2070 and 2070-2100.

Figure 1.11. shows the results of the spatial distributions on the Iberian Peninsula of the change in mean seasonal surface air temperature (at a height of 2 metres) in relation to the mean values simulated for the 1960-1990 period, considering the three thirds of the 21st century mentioned. The spatial distribution of the changes is presented in a discretised manner, in accordance with the cell sizes of the HadCM3 model. The projections presented correspond to two SRES emission scenarios: A2 and B2.

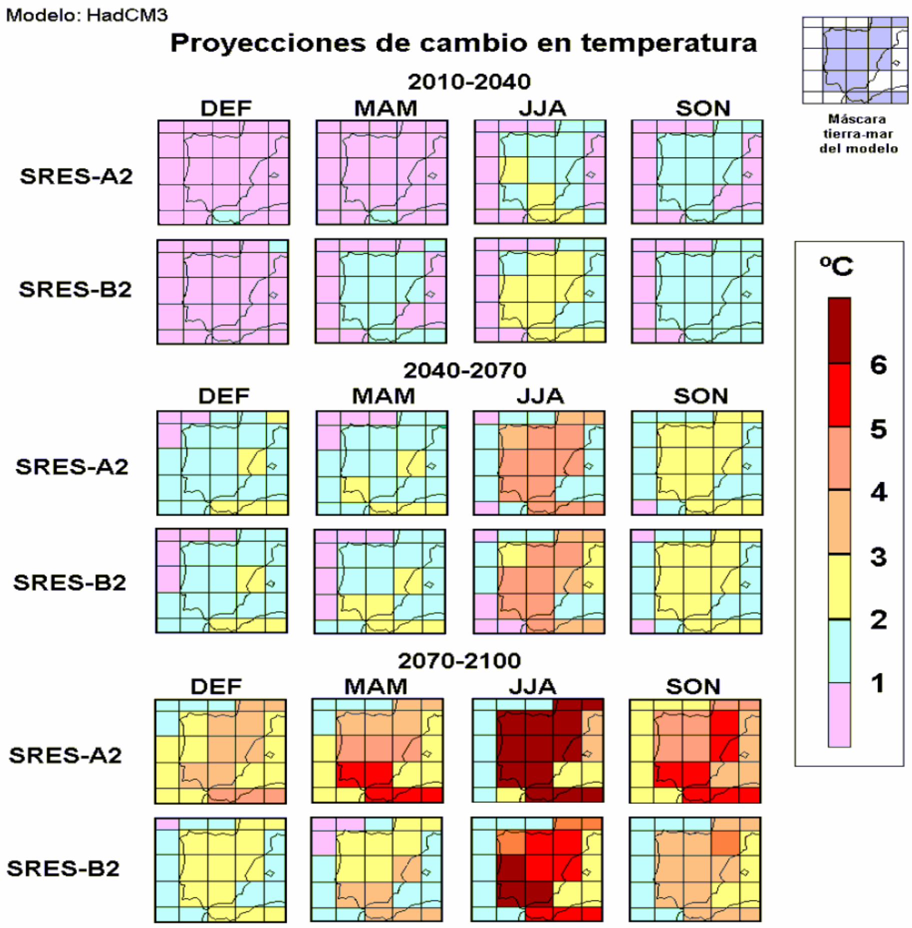

Fig. 1.11. *Projections of changes in air temperature next to the ground (at 2 m), averaged for each season of the year (DJF winter, MAM spring, JJA summer and SON autumn), corresponding to three periods of the 21st century: 2010-2040 2040-2070 and 2070-2100, and to two SRES emission scenarios (A2 and B2). The simulations were made with the HadCM3 model and the results were taken from the IPCC-DDC. In the upper right-hand corner appears the mesh of the model over the Iberian Peninsula, in which the shaded grids correspond in the model to continental area and the white ones to the ocean.*

What is seen more clearly in the figure is a progressive warming throughout the century in the whole region, although the intensity and cadence of this is different, depending on zones and SRES scenarios. This warming is generally more intense and rapid in the summer months (JJA) than in the winter ones (DEF), in scenario A2 than in B2 and in the inland areas than in the coastal ones. The progressiveness of the warming is almost linear in all the zones, although it is a little more accelerated at the end of the 21st century than at the beginning. In most of the Peninsula, the rhythm of the increase in mean temperatures is between 2 and 3ºC every 30 years in the summer months and between 1 and 2ºC in the winter ones, the highest values corresponding to the A2 SRES scenario. The maximum increases in mean seasonal temperature in the last third of the century exceed 6ºC in summer in the whole Peninsula in scenario A2, and in the Southwest in scenario B2. The average warming in the winter months for this period, however, remains below 4ºC in the SRES-A2 and below 3ºC in the SRES-B2.

Finally, it can clearly be seen that differences in warming between the two emission scenarios increase throughout the century.

Changes in precipitation generally present greater spatial variability when they are expressed in percentages. This is due, to a great extent, that current climate precipitation in some areas is so scarce, that a small future climate change is seen in an artificially high percentage. This is why it is preferable to analyse changes in rainfall using differences between values for future climate and for the present one. Obviously, this type of analysis has a disadvantage, in that one same change in absolute values would have greater relative importance in a dry area than in a rainy one. But, on the other hand, the values of absolute change facilitate a more direct quantification of alterations of water availability in any of the areas. Thus, figure 1.12 presents the absolute changes projected in seasonal precipitation throughout the century in relation to the period 1960-1990, expressed in mm/day. In order to deduce the changes in precipitation accumulated in each season, the values in mm/day would have to be multiplied by the number of days of this period, which is 90, because in the simulations with climate models, the years are considered with a uniform duration of 360 days.

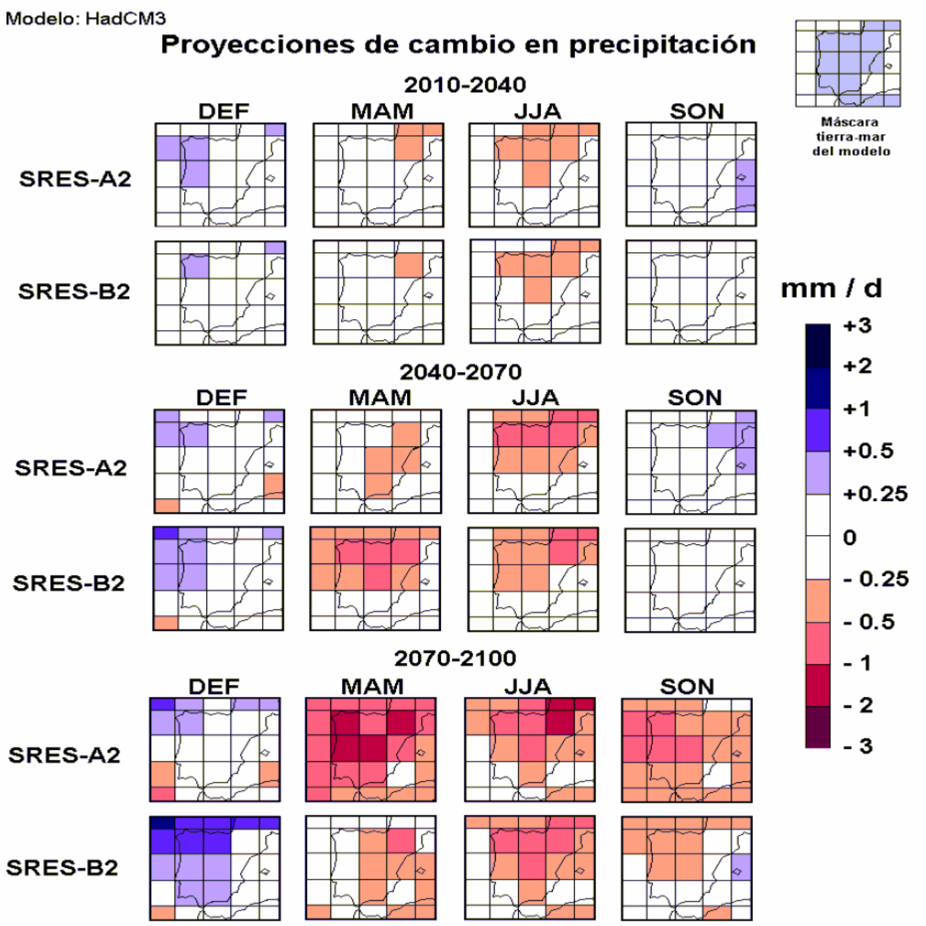

Fig. 1.12. *Projections of changes in mean precipitation (in mm / day), averaged for each season of the year (DJF winter, MAM spring, JJA summer and SON autumn), corresponding to three periods of the 21st century: 2010-2040 2040-2070 and 2070-2100, and to two SRES emission scenarios (A2 and B2). The simulations were made with the HadCM3 model and the results were taken from the IPCC-DDC. In the upper right-hand corner appears the mesh of the model over the Iberian Peninsula, in which the shaded grids correspond in the model to continental area and the white ones to the ocean.*

In contrast with the changes simulated for temperature, which always have a positive sign (warming), those for precipitation do not have the same sign in the different zones and times of year. Thus, changes in the amount of precipitation in the winter months (DEF in the figure) generally have a positive sign in all the zones of the Iberian peninsula, and this occurs for the two emission scenarios considered. In the other seasons, however, above all in spring and summer, there is a predominance of changes with a negative sign, that is, a decrease in the amount of rainfall in the climate projected, compared with the present one. Another characteristic of the evolutions of changes in seasonal rainfall throughout the century is that they generally do not present as much linearity in the tendency as in the case of temperatures. Thus, for example, in scenario B2, the decrease in rainfall in spring is somewhat greater in the middle third of the century than in the final third. Other non-linear behaviour patterns in the temporal evolution of changes in seasonal rainfall can be seen in determined cells of the AOGCM situated over the Iberian Peninsula. Noteworthy among these is the case of the East and Northeast of the Peninsula in scenario A2, in which the model projects rainfall increases in autumn in the first two thirds of the century and decreases in the final third.

Comparing the changes in seasonal rainfall projected for the two emission scenarios, the winter increases can generally be seen to be smaller and the decreases in spring and summer bigger in A2 than in B2. However, an exception to this general behaviour can clearly be observed in the changes projected for the middle third of the century during spring, when the opposite occurs.

It is precisely the spatial and temporal irregularities appreciated in the projected changes in rainfall that indicate the greater uncertainty that they present, if we compare them with those obtained in the case of temperatures. This is essentially due to the fact that the occurrence of rainfall in any place and at any time is associated with physical processes that are more difficult to simulate correctly with the models, whereas the processes determining air temperature close to the ground are more conditioned by the seasonality of solar radiation reaching the planet throughout the year, the calculation of which is made with a high degree of certainty. The most reasonable procedure for reducing the uncertainty of projected changes in rainfall lies in considering the results provided by an ensemble of AOGCMs.

In accordance to this, we considered the results from six AOGCMs included in the DDC-IPCC database (http://ipcc-ddc.cru.uea.ac.uk/dkrz/dkrz_index.html). Specifically, these are the models called CCGM, CSIRO, HadCM3, NIES2, ECHAM4 and GFDL, the characteristics of which were shown in Table 1.3. In order to make this analysis in a simple way, we only considered the results of the changes in seasonal temperature and rainfall obtained in the cell of the mesh of each model that includes the centre of the Iberian Peninsula. It must be kept in mind that the grid of the six models considered have different horizontal resolutions (see Table 1.3). Figure 1.13 illustrates the comparative size and location of the cell considered for each de AOGCM.

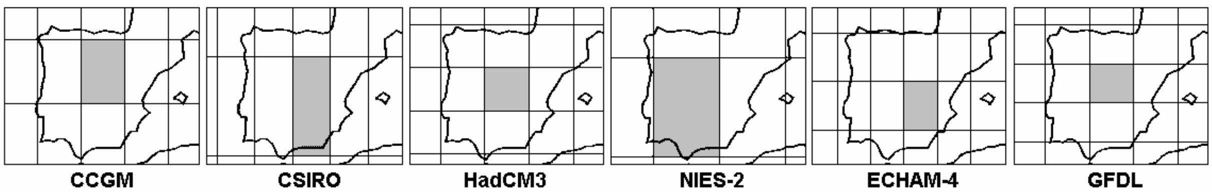

Fig. 1.13. *Illustration of the meshes of the six AOGCMs considered. In order to make the comparison we took the simulated results for each model in the grids which include the centre of the Peninsula.*

The changes in the mean seasonal temperatures projected for the centre of the Iberian Peninsula in each third of the 21st century, the model and emission scenario are shown in figure

1.14. Comparing the results of the six models, differences in the changes simulated for each one are observed, but so are similarities. The differences lie in the specific values of temperature change for each period, season and emission scenario. The NIES2 model is the one that generally simulates the biggest warming, whereas the differences between the others are somewhat smaller. However, it must be taken into account that this lack of coincidence in the values of temperature change could partly be related to the different spatial resolution over the Iberian Peninsula of the different AOGCMs. All the models coincide in the progressive warming throughout the century in relation to the 1960-1990 period. In all of these, then, maximum warming is projected for the summer months and the minimum for winter, and it can also be seen that in emission scenario A2, the temperature increases are greater than in B2. The qualitative coincidence in this set of results is indicative of their high degree of certainty.

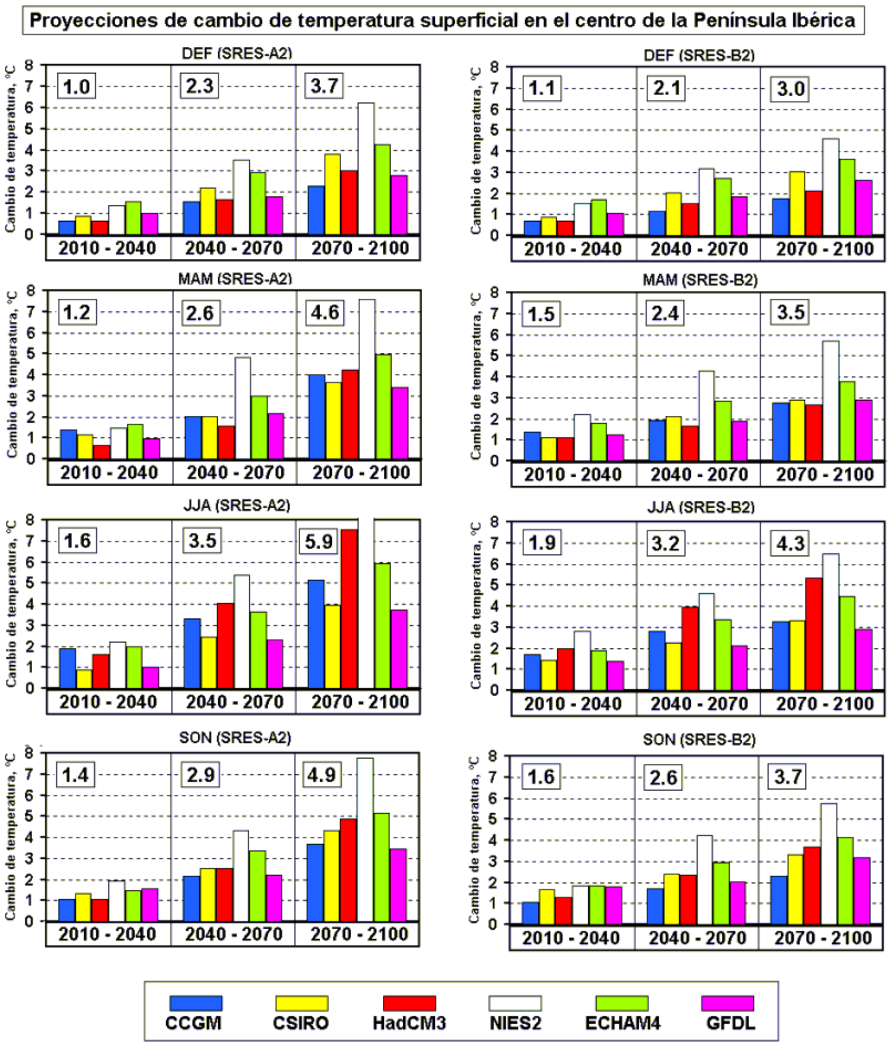

Fig. 1.14. *Changes projected by six AOGCMs in surface mean air temperature (ºC) in the grid of each one, which includes the centre of the Peninsula (see figure 1.13). The results are seasonal averages (DJF winter, MAM spring, JJA summer and SON autumn) and correspond to two emission scenarios (A2 in the left-hand column and B2 in the right.-hand one). Each figure shows the changes in each third of the 21st century in relation to the present climate. The average values of the set of six models considered are shown in the box.*

Considering the values of the mean temperature increases of the set of models framed in figure 1.14, it can be seen that the highest rhythm of seasonal warming corresponds to the summer of scenario A2 and the lowest one to the winter months of scenario B2. It can also be seen that in scenario A2 the warming rhythm accelerates in all seasons as the century elapses, whereas in scenario B2, the evolutions of warming generally present a more linear tendency.

Figure 1.15 shows the comparison between the changes projected by the six AOGCMs for rainfall in the centre of the Peninsula. Therein, more discrepancies can be seen between the models, which indicates the lower degree of reliability of the projections of changes in rainfall in relation to those of temperature. This, however, could be partly due to the greater spatial variability of the changes in rainfall simulated by all the models, which makes the different sizes of the cells over the Peninsula more determinant than in the case of changes in temperature. Some similarities can, however, be observed in the results of the AOGCMs analysed. Thus, for example, almost all of them coincide in projecting decreases in rainfall in the future climate in relation to the 1960-1990 period, although some models simulate certain seasonal positive changes. Likewise, a majority of models project a progressive decrease in seasonal rainfall in scenario A2 throughout the century, although this behaviour is not evident in scenario B2.

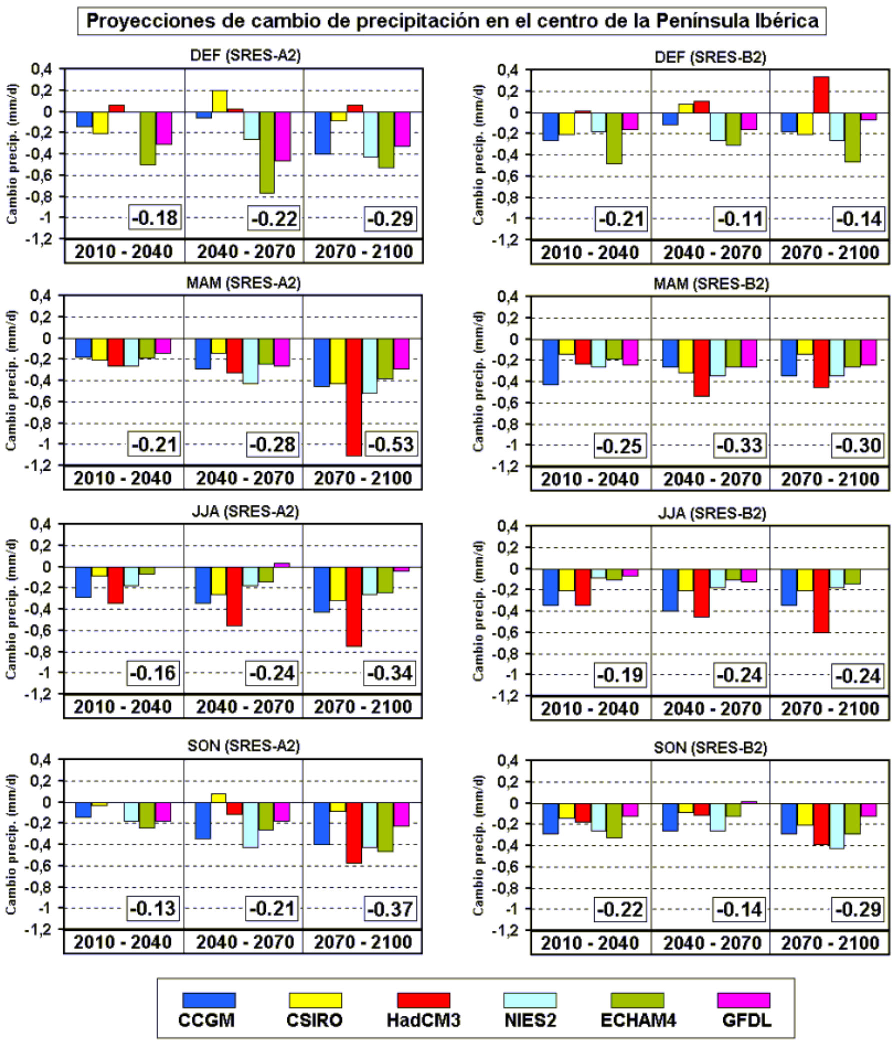

Fig. 1.15. *Changes projected by six AOGCMs in mean precipitation (mm / day) in the grid of each one, which includes the centre of the Peninsula (see figure 1.13). The results are seasonal averages (DJF winter, MAM spring, JJA summer and SON autumn) and correspond to two emission scenarios (A2 in the left-hand column and B2 in the right.-hand one). Each figure shows the changes in each third of the 21st century in relation to the present climate. The average values of the set of six models considered are shown in the box.*

In the centre of the Iberian Peninsula, the HadCM3 model simulates the greatest decreases in rainfall in spring, summer and autumn, whereas it projects increases in rainfall in winter months. The progressiveness of these changes throughout the century is more in this model than in the others. The model showing the lowest projections of changes in annual rainfall is the CSIRO, but the progressiveness of these changes is quite irregular. Emphasis has been placed on this characteristic because the values of the changes included in the figure correspond to differences between seasonal rainfall simulated for each third of the 21st century and those simulated for the 1960-1990 interval. Thus, if the value of a change were greater in a previous third than in a subsequent one, this would signify a relative increase in rainfall between the first one and the second one.

Considering the joint averages of the six AOGCMs, the values of which are framed in figure 1.15, it can be seen that in scenario A2, the progressiveness of the changes is regular in all the seasons of the year. Which means to say, the absolute value increases throughout the century. Calculating the units of change used in the figure, the results of average distribution of annual rainfall changes in the three periods of the century are: 61.2, 85.5 and 137.7 mm/year. However, what can be seen in scenario B2 are absolute values of annual change which are lower in the middle third of the century (78.3, 73,8 and 87,3 mm/year). This means that the middle third would be less dry than the other two. Furthermore, this different progressiveness of the change in annual rainfall throughout the century in both scenarios (A2 and B2) can be seen in the results of most of the AOGCMs considered, which endows this result with a degree of certainty.

1.3.4. Regional climate models

Although the results of climate projections obtained with different AOGCMs present reasonable similarities at global scale, when regional scales are considered, distributions of temperature and, above all, rainfall present clear discrepancies, as was pointed out in the previous section. This reduced reliability at regional scale can be attributed, to a great extent, to the insufficient spatial resolution of the AOGCMs and to the use of physical parametrisations not well adapted to mesoscale processes. Low spatial resolution can distort the lines of the coast and smooth the orographic features. Besides, it has already been pointed out that the models cannot realistically reproduce atmospheric processes with a similar or smaller size than that of the cells in which the domain is discretised. Furthermore, it must be kept in mind that certain physical parametrisations of the AOGCMs have been developed and validated for the broad spatial resolution that they use. This is why they are not usually suitable for reproducing smaller-scale atmospheric processes, some of which could be the ones that most contribute to the characteristics of local climate. In particular, the climates of the Iberian Peninsula are the result of the action of global atmospheric circulation, of the interactions between this macroscale flow and orography, of sea-land contrasts and of other more local effects (Castro *et al*. 1995). But the present AOGCMs are incapable of reproducing these climate features on the Peninsula. An illustrative example is shown in figure 1.16, where the distributions of seasonal temperature and rainfall simulated by the HadCM3 model for the 1961-1990 period are compared with the climatologies for this period. It is obvious that the climate features at regional scale of the Peninsula have not been reproduced because the low spatial resolution of the AOGCM does not permit this. But increasing the resolution of the AOGCMs would involve an increase in computing time and also the adaptation of the physical parametrisations to this higher resolution at all the latitudes of the planet. The solution to the first problem depends on the availability of sufficiently fast and powerful computers, although no results of global climate models at resolutions greater than 100 km yet exist. But to solve the second problem, perhaps we will have to wait a bit longer. Consequently, in order to obtain more suitable approximations to climates at regional or sub-regional scale, other techniques are currently applied, based on the simulations with the AOGCMs.

These techniques can be arranged into two categories: statistical downscaling methods and regional models. The former translate the information provided by the AOGCMs into high-resolution descriptions of the climatic variables, by means of multivariable statistical regressions between series of mean values of temperature and precipitation variables observed in stations included in one cell of the global model and the mean values of other atmopspheric variables (predictors) simulated therein. These regression equations are used to infer the corresponding climatic information in each area, with the use of values simulated by the AOGCM for disturbed climate (Sailor and Li 1999 or von Storch and Zwiers 1999, among others). The results obtained with statistical methods should be analysed with caution, because they are based on the implicit supposition that spatial correlation between local variables and predictors within one cell of the model, obtained under present climate conditions, is not altered after an appreciable global climatic change, and furthermore, the results critically depend on the predictors chosen (Huth 2004).

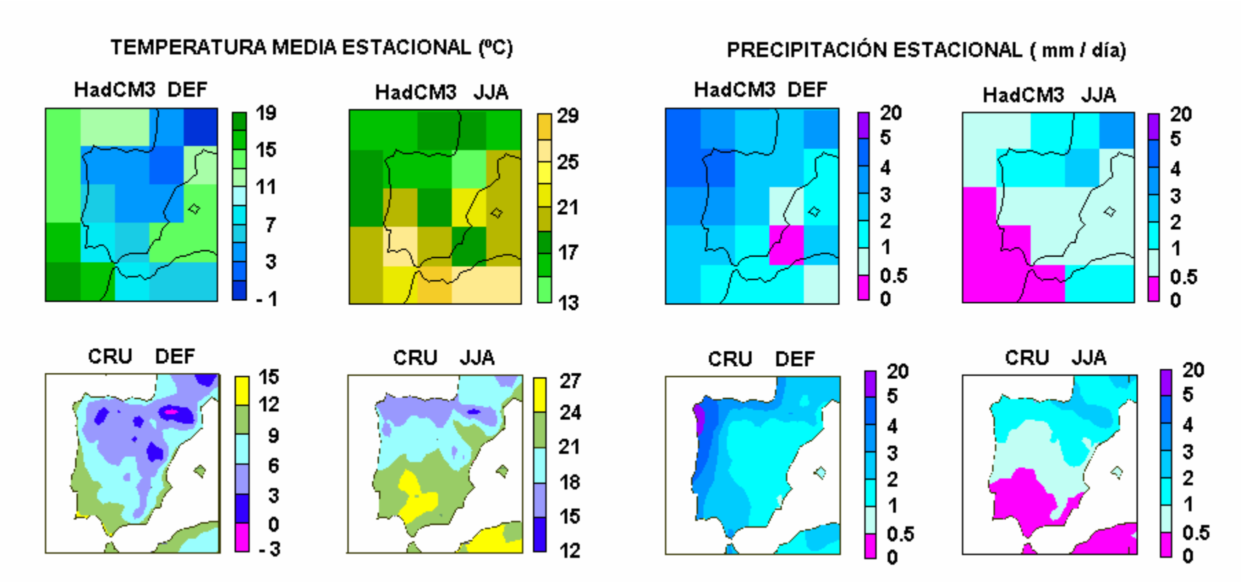

Fig. 1.16. Comparison between mean temperatures (in ºC) and precipitation (in mm /day) averages in winter (DJF) and summer (JJA) simulated by the AOGCM HadCM3 (upper row) and the climatology designed by the Climate Research Unit (CRU) of East Anglia University (lower row). In both cases, the period is 1961-1990. Note that the colours and values in temperature scales are different on each map, but those for precipitation are the same.

Regional climate models (hereinafter RCM) are considered as the most promising technique for making reasonable projections of climate change at regional scale (IPCC 2001). The RCM are essentially similar to the atmospheric sub-model of any AOGCM, but they are applied to a limited area of the planet, with more resolution, that is, with the use of smaller cells. They are nested in the mesh of the global model (figure 1.17). This means that in the RCM, the initial values of the variables simulated and their temporal evolution in the domain boundaries are derived from results obtained by an AOGCM. In short, the RCM are feeded through the boundaries with values simulated by the AOGCMs. The procedure currently followed therefore consists of using the AOGCM output data to simulate the response of global circulation to macroscale forcings and the RCM in order to take into account smaller-scale forcings than the size of the cell in the AOGCM, in accordance with the principles of physics, and to highlight the simulation of atmospheric circulation patterns and climatic variables at finer spatial scales (IPCC 2001).

The RCM technique, initiated at the beginning of the last decade of the 20th century (Dickinson *et al*. 1989), is currently used for a whole range of applications, from palaeoclimatic studies to projections of anthropogenic climate change. They provide results with high spatial resolution (between 50 and 20 km) by means of time-slice simulations of several decades and are capable of describing climatic feedback mechanisms at regional scale. The current RCM are generally adapted versions of limited area models used operatively for high-resolution weather forecasting. There are, however, RCMs that link atmospheric processes and other components of the climate system (ocean, hydrology, vegetation, etc.).

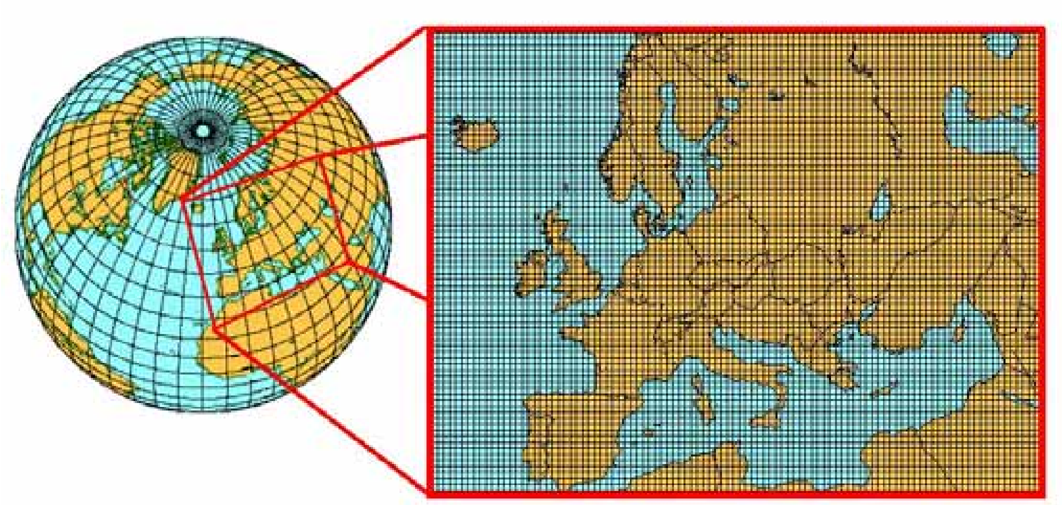

Fig. 1.17. *Example of the application domain of an RCM over Europe with a grid of 50 km. The nesting technique consists of providing the RCM with information on the evolution of the atmospheric variables in the lateral boundaries. This information is obtained previous to the simulation with an AOGCM which uses a grid with lower resolution (bigger-sized grids)*

It must be remembered, however, that an RCM cannot correct errors generated by the AOGCM in which it is nested. For this reason, an AOGCM should be chosen that has been well validated and that realistically represents the features of global circulation affecting the region in question, or the nesting should be considered within a set of different AOGCMs. It is also important that the RCM include suitable physical parametrisations in order to simulate moist convection processes, energy exchanges between the air and the ground or radiative effects of the clouds, of GHGs or of aerosols. Finally, the choice of the size of the cells of the RCM mesh should be taken as a compromise between the scale of those atmospheric processes most influencing the climate of the region in question, and the available computing power. In spite of the fact that RCMs can be applied to a limited area of the planet, the computing time is much greater than what is needed by an AOGCM in order to simulate the same period. This is why the current RCMs do not usually simulate periods of more than a few tens of years (usually 30 years), although the increase in computing power will enable these periods to be lengthened before long.

1.3.5. Future climate projections in Spain using an RCM

This section presents the results obtained from a series of simulations with the regional climate model known as PROMES (Gallardo *et al*. 2001). This is a model that numerically resolves the primitive equations of atmospheric dynamics and includes suitable parametrisations of the physical processes of radiative exchange, of cloud formations and precipitation and of turbulent exchange of mass, momentum and energy between the atmosphere and the surface. They are integrated considering a Lambert conformal horizontal projection in an area of 6,000 x 4,500 km covering almost all of Europe and North Africa, including the Canary Isles archipelago. The horizontal resolution of the simulations, the results of which are presented here, is 50 km. In the vertical direction the RCM PROMES considers 35 layers of varying thickness, much less in the lower layers of the atmosphere.

The simulations were carried out within the framework of the PRUDENCE research project, funded by the V Framework Programme of the EU. In this project, the results were compared of eight RCMs developed in different European centres or universities (Christensen *et al*. 2002). Specifically, the Spanish modelling group participating in this project (MOMAC Group from Castilla La Mancha University in Toledo) is the one that created the PROMES model. All of these European RCMs were implemented and nested in the HadAM3H global atmospheric model, developed in the Hadley Centre for Climate Prediction and Research in the United Kingdom (Pope *et al*. 2000), which uses a horizontal resolution of approximately 140 km at the latitudes of the Iberian Peninsula. This global atmospheric model uses the ocean surface temperatures provided by the aforementioned AOGCM HadCM3. Although the simulation with the HadAM3H global atmospheric model covers the 1950 – 2100 period, the experiments with the RCMs nested therein were done covering two time-slice 30-year periods, due to the aforementioned greater computing effort required by these models. One corresponding to present climate conditions (1960-1990), in which the current levels of atmospheric GHGs and aerosols were considered, and another relating to the last third of this century (2070-2100), taking into account the SRES-A2 and SRES-B2 emission scenarios. Consequently, each RCM did a total of three experiments of 30 years each. For the choice of the mentioned global atmospheric model in which the RCMs were nested, the generally acceptable quality of the results they present was taken into account.

Using the set of numerous output variables of the RCM PROMES, to illustrate the impact on Spain's climate of the projected climate change, this section presents results corresponding to mean daily temperatures of surface air (2 metres above ground) and accumulated daily precipitation for each season of the year. In the first place, the results of the simulation using PROMES corresponding to the 1960-1990 period was commented upon (herein after called control simulation) and these results were compared with climatological values derived from observations during this period. This gives us an idea of the degree of fit with reality of the simulations with this RCM. Subsequently the results of the two climatic projections (A2 and B2) were shown as the difference between the values obtained for each scenario and those simulated for the 1960-1990 period. Likewise, we present the results of seasonal changes in evapotranspiration and wind speed for each scenario, in relation to the present climate. Lastly, an analysis is included of projections of changes in climatic extremes associated with temperatures and rainfall.

a) Comparison between control simulation and climatology

Before commenting upon the results of this comparison, the following two statements should be taken into account:

- The climatology with which the results of a RCM control run are compared should be discretised in cells of a similar size to those of the model, in order for the topography of the domain to be similar. This is why we considered the climatology developed by the Climate Research Unit of East Anglia University (United kingdom) based on values observed daily from 1960 to 1990 in a set of weather stations in Spain and Portugal (New *et al*. 1999). This database can be found in Internet at the address *http://ipcc-ddc.cru.uea.ac.uk*. With these specific observations, the mean values corresponding to cells of 0.5º x 0.5º in latitude-longitude were assigned. Consequently, these are spatial distributions of climatological values resulting from a spatial interpolation method following certain objective criteria, not the actual ones.

- The values of the control simulation with the PROMES model are the result of the nesting of this RCM in the experiment made with a global climate model, considering that the atmospheric component of the climate system contains concentrations of GHGs and of aerosols corresponding to the concentrations observed in the 1960-1990 period. Which means to say that we cannot expect the daily sequence of the global circulation fields of the atmosphere and the ocean to correspond with what actually occurred, as we are dealing with a reproduction of mean climatological values.

Consequently, the comparison should be made by analysing the similarity between the spatial distributions of 30-year averages of the variables considered, instead of between values corresponding to a determined point, month or year. Furthermore, as climatology only includes values in continental areas, where there are observatories, it will be seen that a resolution 0.5º x 0.5º does not permit good correspondence between the situation of the Balearic Isles or the Canary Isles and that of the cells in which the climatological values are assigned.

Figure 1.18 allows for a graphic comparison between the distributions of seasonal average values of mean daily temperature on the Iberian Peninsula and on the Balearic Isles. A good level of similarity is generally observed between the simulated values and climatology. The model, however, tends to highlight more the effect of orography in the temperatures, so that in the higher areas the model simulates lower temperatures than the climatological values. This bias is perceived in all the seasons of the year, although it is more obvious in summer and autumn, resulting in a bias of 2 to 4 degrees at elevations of over 600 m. However, in the rest of the zones and stations, the simulated values are more similar to the climatological ones. On the islands, the differences remain below 2 degrees. However, it must be remembered that the resolutions of the model and of the climatology do not allow the smaller islands to be suitably resolved. This general behaviour has also been observed in the control simulations (1960-1990 period) made by the other RCMs used in the aforementioned PRUDENCE European project.

The distributions of the mean seasonal precipitation simulated and the climatological ones are shown in figure 1.19. Although the model presents more spatial variability than climatology, it can be seen that they acceptably reproduce the North-South gradients in summer and the West-East ones in the other seasons of the year. The greater variability observed in the results of the model appear to be due to the fact that this tends to increase orographic effects. The simulated values of seasonal precipitation on the Atlantic coast generally correspond very well with those of climatology. However, the ones simulated in the south-western half are generally lower than the climatological ones. The simulated distribution of precipitation for the summer season is the one that shows the greatest similarity with climatology, whereas the greatest differences are noted in winter, especially in the Centre and East of the Peninsula. However, analysing the simulated annual evolutions of precipitation for different sub-regions of the Peninsula, it has been seen that they acceptably reproduce climatological values, discriminating well between the most and least rainy seasons of the year for each of the zones of the Peninsula.

To summarise, it could be said that the model tends to highlight topographic effects more than climatology developed by the CRU , in spite of the fact that the spatial discretisation of the terrain is very similar in both cases: 50 km in the PROMES model and 0,5º latitude-longitude in the climatology of the CRU. It must also be remembered that the CRU climatological values are the result of a spatial interpolation treatment among those registered on specific observatories, which are generally not located in the higher areas of the territory. For this reason these should also be considered to present a certain degree of smoothing in mountain areas. However, the most notable aspect of this comparison between the values simulated by the RCM PROMES and the CRU climatology for the 1960-1990 period is that the model acceptably reproduces the different climate regimes of the Iberian Peninsula. Consequently, we can assume that the results of the simulations with future climate scenarios made with the aforementioned RCM, which is now shown, present a reasonable degree of reliability with regard to their capacity to regionalise climatic changes simulated at global scale by the AOGCM HadCM3.

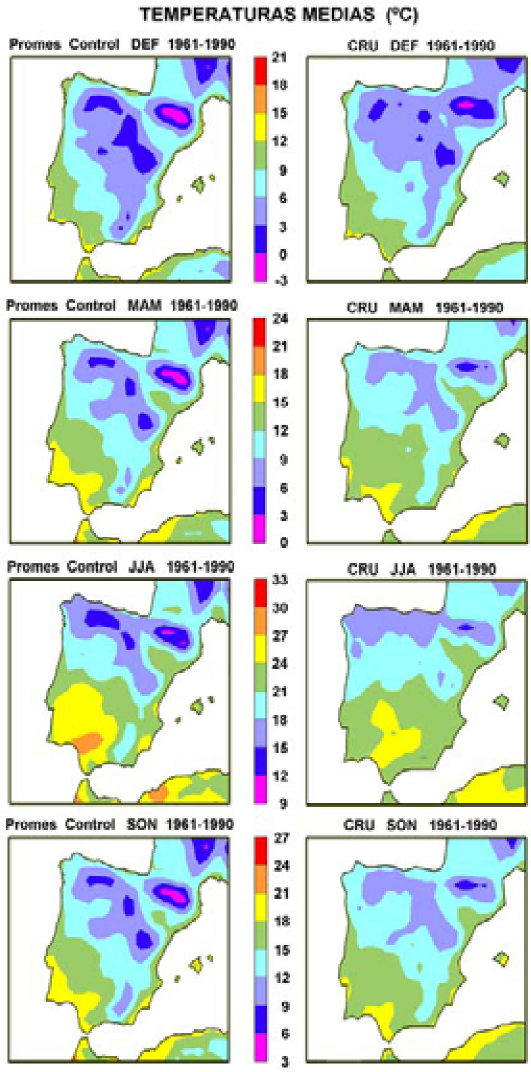

Fig. 1.18. *Comparison of daily mean temperatures (in ºC) simulated by the RCM-PROMES (left-hand column) and designed by the CRU (right-hand column) based on climatological data for the period 1961-1990. Each figure corresponds to averages for one season of the year: (DJF winter, MAM spring, JJA summer and SON autumn). The colour scales include different temperature values for each season.*

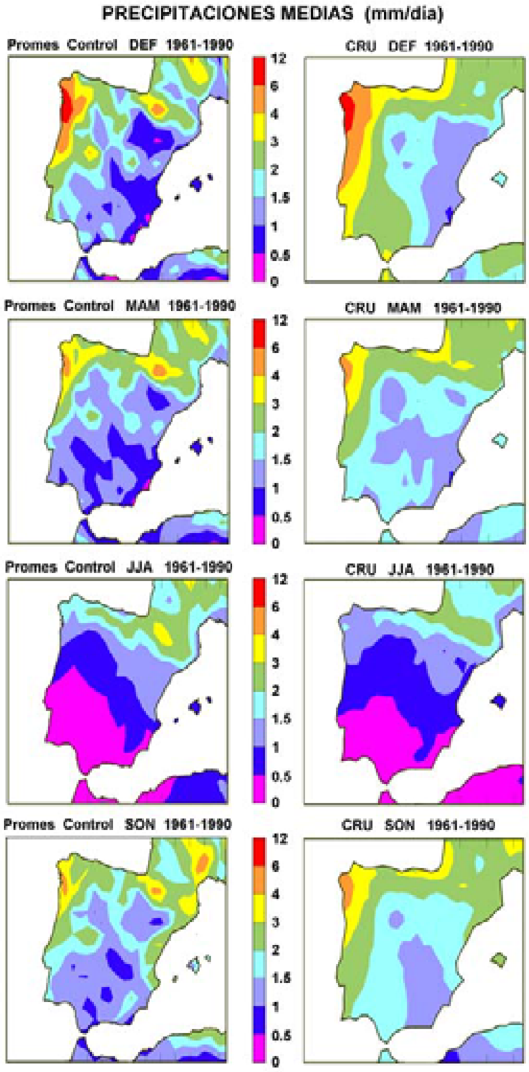

Fig. 1.19. *Comparison of mean seasonal precipitation (en mm/day) simulated by the RCM-PROMES (left-hand column) and designed by the CRU (right-hand column) based on data for the period 1961-1990. Each figure corresponds to one season of the year: (DJF winter, MAM spring, JJA summer and SON autumn).*

b) Changes in mean temperatures projected in the future climate scenarios

This sub-section includes the changes projected for the seasonal averages of mean daily temperatures in the two emission scenarios considered (SRES-A2 and SRES-B2), corresponding to the last third of the XXI century (2071-2100 period), with respect to the modelled values in the control simulation (1961-1990 period). Although it cannot be assumed that the evolution of these changes throughout the century shows a perfectly linear growing behaviour pattern, it seems reasonable to presume that in periods previous to this one, these changes would register lower values, as can be deduced from the results obtained with the AOGCMs.

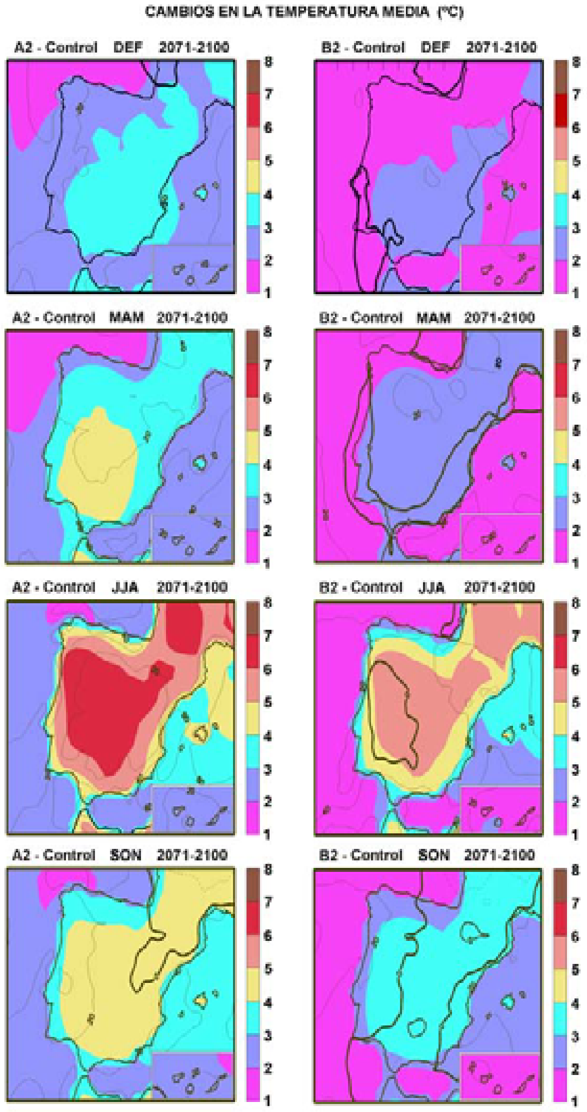

Fig. 1.20. *Projections of change in daily mean surface air temperature (ºC), averaged for each season of the year (DJF winter, MAM spring, JJA summer and SON autumn) in the Iberian Peninsula, Balearic Isles and Canary Isles (lower right-hand corner on each map), corresponding to two SRES scenarios: A2 in the left-hand column and B2 in the right-hand column. The values correspond to differences between the simulation of the period 2071-2100 and the control one (1961-1990). The isolines in the figures show the percentages of changes in interannual variability (positive in continuous line, negative in broken line and zero in continuous thick line).*

The projections of seasonal change in mean daily temperatures are shown in figure 1.20. The general behaviour pattern shows that the most intense temperature increases correspond to the scenario SRES-A2, which is the one with the highest emissions of GHGs. The differences between scenarios A2 and B2 remain at around 1ºC. The winter months are those that present smaller increases in daily temperature, with values of between 2 and 4 ºC for scenario A2 and between 1 and 3ºC for scenario B2. The spatial distribution of these changes in winter is similar in both scenarios, the smallest increases corresponding to the Northeast of the Peninsula and the Canary Isles, and the biggest ones to the south-eastern half of the Peninsula. The season in which temperature increases are greatest is summer, values exceeding 6ºC in scenario A2, and over 5ºC in B2. Such big changes occur in the inland zone of the Peninsula. A clear gradient between the periphery and the inland zone can be perceived, which could be related to the regulating effect of the sea breezes. This can also be said of the two archipelagos, although the small size of these does not allow us to perceive this gradient. In spring and autumn, the projected increases reach intermediate values between the winter and summer ones. Increases in autumn, however, are greater than those of the spring, particularly in scenario B2. Although they are not shown graphically, the projected changes for the seasonal averages of maximum and minimum daily temperatures present a spatial distribution similar to those of mean temperatures. However, the values of the changes are around 1ºC higher for the maximums than for the minimums, those of the latter being similar to those of mean temperatures. This means that the range of daily thermal oscillation increases compared to the present climate. This behaviour can be seen in all the seasons and in most of the areas of the territory, except on the islands or very close to the coast. In their essential aspects, the previous results are similar to those obtained by Räisänen *et al*. (2004) who used another regional climate model within the framework of the aforementioned European project PRUDENCE.

c) Changes in mean precipitation values projected in future climate scenarios

We will now analyse the changes projected for mean seasonal rainfall for the two emission scenarios considered (A2 and B2) corresponding to the period 2071-2100, taking as a reference the values modelled in the control simulation (1961-1990). Before presenting the results, it should be pointed out that it would not be correct to use a simple temporal interpolation to deduce changes in rainfall in periods previous to 2071-2100. This can be seen in the results obtained with the AOGCMs represented in figure 1.15, where it can be observed that no AOGCM simulates a uniform tendency of change in seasonal rainfall on the Iberian Peninsula throughout the 21st century.

Figure 1.21 shows the values of the seasonal changes expressed in mm/day. Multiplying these values by the number of days in each season, which is 90, because in the climate simulations with models the years are considered with a uniform duration of 360 days, the changes can be deduced in the total amounts of seasonal rainfall. What can be appreciated more clearly in the figure is that the changes have a greater absolute magnitude in scenario A2, regardless of their sign. Thus, in winter there are increases in the Northwest of the Peninsula that exceed the value of 1 mm/day in scenario A2, whereas in B2 these remain below 0.5 mm/day in this region. Something similar occurs in autumn, but in the Northeast of the Peninsula. This result tallies with that obtained by Sumner *et al*. (2003), who used the simulations made with another global model (ECHAM4 of the Max-Planck Institut für Meteorologie in Hamburg). Apart from these two exceptions, the changes in precipitation in Spain have a negative sign. This means that decreases in seasonal precipitation in relation to the present climate are projected for the last third of the 21st century, which are generally of greater magnitude in scenario A2 than in B2, except for the vicinity of the Pyrenees for the summer months, in which the magnitude of the changes are similar in both scenarios. In the Canary Isles, no appreciable change in total precipitation can be appreciated in any season of the year.

d) Projected changes in evapotranspiration and wind module

We now present the differences obtained between the seasonal averages of daily surface evapotranspiration projected for the last third of the 21st century, and the ones simulated in the control experiment (present climate). It must be mentioned that the amounts of water that evaporate from the surface were simulated with a parametrisation scheme implemented in the PROMES regional climate model. The scheme therefore provides a good link between atmospheric and edaphic processes. This scheme, developed by Decoudre *et al*. (1993), does not only calculate the amount of water that evaporates from the ground, but also the water that tanspires from the different types of plant cover included in each cell of the model (Arribas *et al*.

2003). It should also be pointed out that in all the simulations (control and scenarios) the same type of land uses have been maintained.

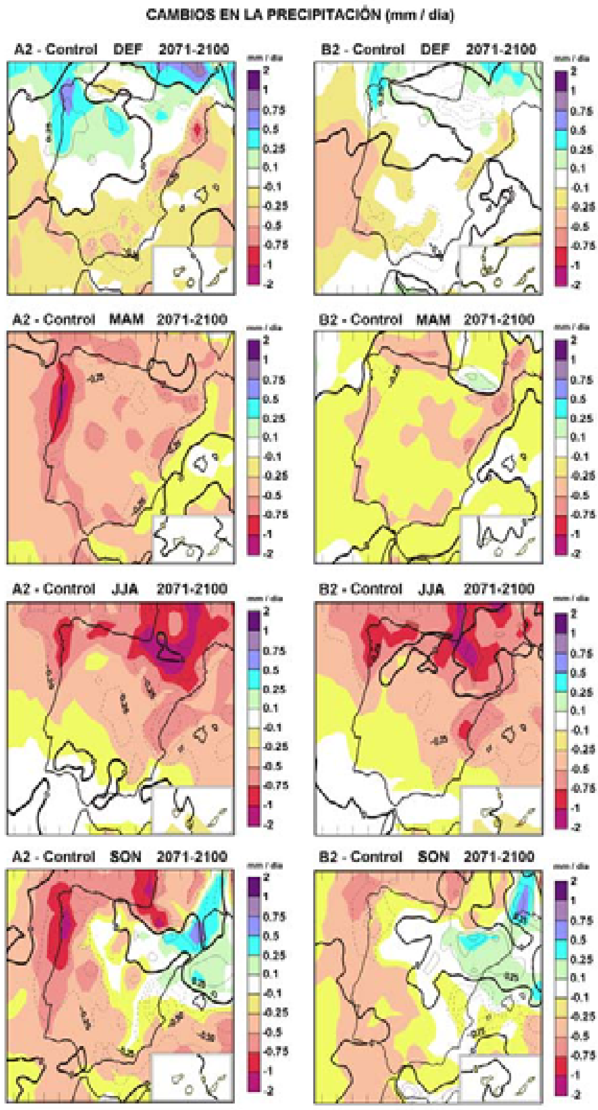

Fig. 1.21. *Projections of changes in precipitation (in mm/day) averaged for each season of the year (DJF winter, MAM spring, JJA summer and SON autumn) in the Iberian Peninsula, Balearic Isles and Canary Isles (lower right-hand corner on each map), corresponding to two SRES scenarios: A2 in the left-hand column and B2 in the right-hand column. The values correspond to differences between the simulation of the period 2071-2100 and the control one (1961-1990). The isolines in the figures show the percentages of changes in interannual variability (positive in continuous line, negative in broken line and zero in continuous thick line).*

The results obtained from the two emission scenarios considered (A2 and B2) present a notable percentage decrease in the average amounts of water evapotranspired in summer and autumn in most of the Peninsula compared with the values obtained in the simulation of the present climate. The maximum reductions are observed in the southern half of the Peninsula during the summer months, and in some areas these reach values of around 60% in scenario A2 (figure 1.22), whereas in autumn they remain below 40%. In emission scenario B2, the decreases in evaporation are more moderate, and in general these do not exceed 40% in summer and 20% in autumn. In both seasons, a slight increase in evapotranspiration in the northern third of the

Peninsula can be observed, which does not surpass 20% in the two scenarios simulated. In the winter months, however, increases in surface evapotranspiration are projected for practically the whole Peninsula, and in some areas the increases exceed 40%, although in most of the territory, they remain below 20% (figure 1.22). No significant differences are appreciated between the results obtained for the two emission scenarios considered. Lastly, in the spring months, slight decreases in evapotranspiration are obtained in the southern half of the Peninsula (less than 20%) and increases in the northern half, exceeding a value of 40% in the Northeast. With regard to the Canary Isles and Balearic Isles, none of the simulations show significant changes in the seasonal averages of water evaporated from the surface, compared with the values simulated in the control experiment (present climate).

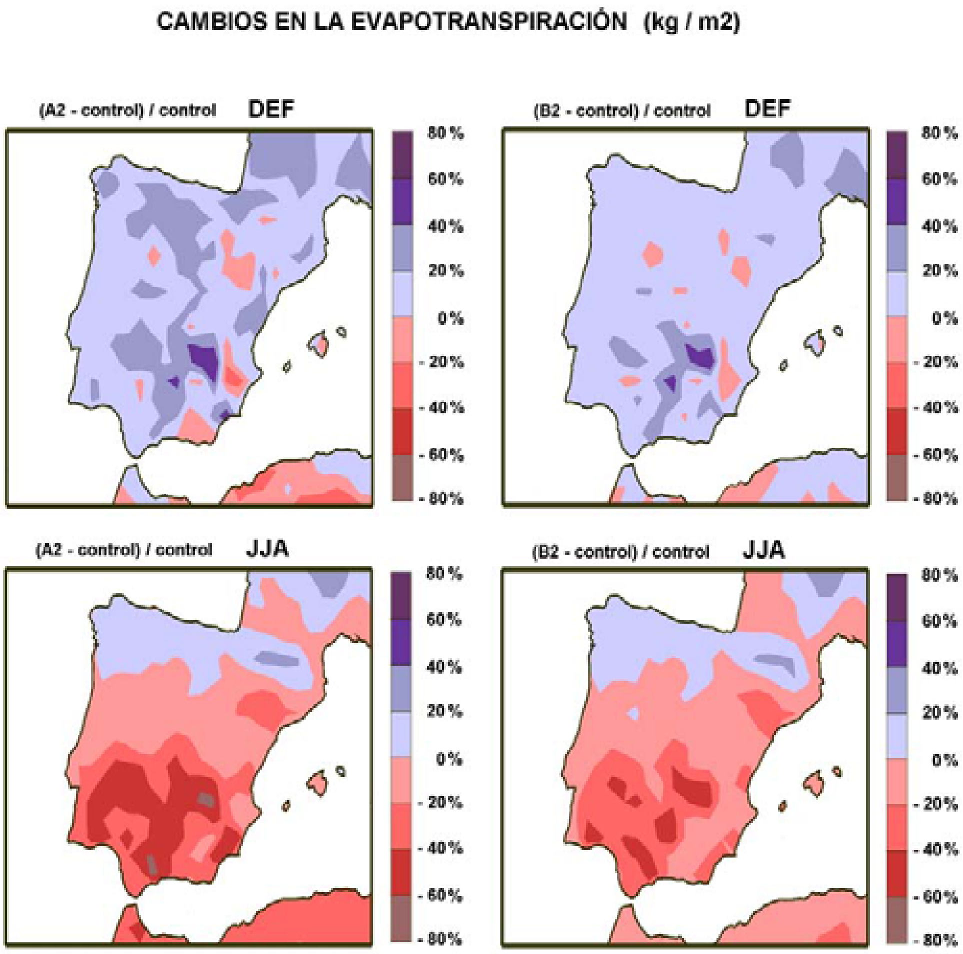

Fig. 1.22. *Projections of percentage change in evapotranspiration in winter (DJF) and summer (JJA) months, corresponding to two SRES emission scenarios: A2 in the left-hand column and B2 in the right-hand column. The values correspond to change percentages between the simulation of the scenario and the control one in relation to the control one.*

In relation to the surface wind module (10m above ground), the percentage changes projected in the two scenarios in relation to the present climate present different signs depending on the time of year, and also different ones on the Peninsula and the Balearic Isles in relation to the Canary Isles. Thus, in summer, a significant increase is observed in the average wind intensity in most of the Peninsula, reaching increases of above 10%, except in the Northwest, where slight decreases are obtained (figure 1.23). But in the other seasons of the year, there is a predominance of negative changes in average wind intensity over the Peninsula and the Balearic Isles, the biggest of these in autumn, with decreases exceeding 10% in the Northeast and 5% in most of the Peninsula. However, in the vicinity of the Gibraltar Straits, increases are projected in the wind module in all the seasons of the year, except in winter. However, the seasonal distribution of the change in wind intensity projected for the Canary isles area is practically opposed to that of the Peninsula. Summer is the time of year in which the projected changes show a negative sign, which means that there is a projected decrease in average wind in the future climate compared with the present one, whereas in the other seasons of the year, increases in average wind intensity are simulated, the biggest one being in spring and winter (figure 1.23). In all cases, the positive and negative differences in the wind module projected in Spain for the end of the century (2071-2100) in comparison with the values of the 1961-1990 period (present climate) are somewhat more accentuated in the simulation of scenario A2 than in B2.

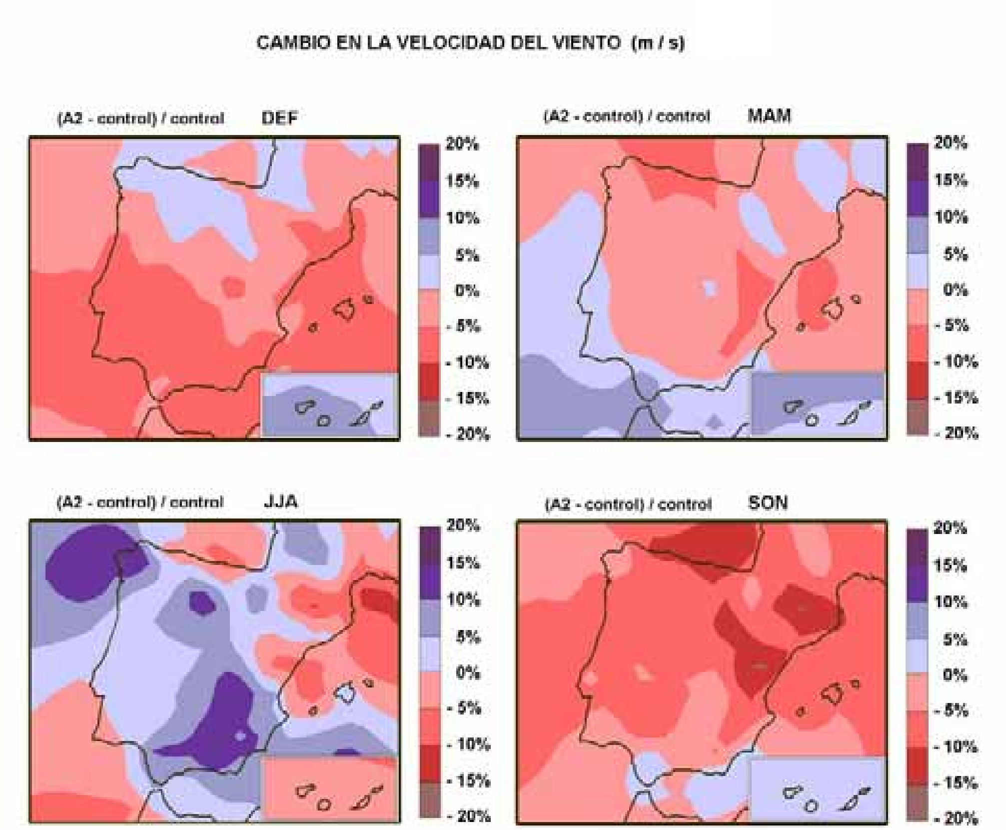

Fig. 1.23. *Projections of percentage change in the surface wind speed module for each season of the year (DJF winter, MAM spring, JJA summer and SON autumn), corresponding to SRES-A2 emission scenarios. The values correspond to change percentages between the simulation of the scenario and the control one in relation to the control one.*

e) Changes in the variability and extremes of temperatures and rainfall projected in the scenarios of future climate

An aspect of the projections of future climate which is as important as changes in mean temperature values or in any other climatic variable, is a possible change in variability in relation to the present climate. Variability is understood as the standard deviation from the temporal statistical average. Different time scales of variability can be considered: inter-seasonal, interannual, or interdecadal. We now present the results obtained from the application of a simple analysis of interannual variability, which consists of considering the value of the following percent ratio:

$$\frac{\sigma_f - \sigma_a}{\sigma_a} \cdot 100$$

where σ_f is the standard deviation from the distributions of monthly temperature averages in the future period (2071-2100) and σ_a of the simulated period of the present climate (1961-1990). Thus, a positive value (or negative one) of this ratio would indicate the percentage of the increase (or decrease) in the variability of monthly temperatures or rainfall in the projected climate, compared with that of the simulations in the control experiment (present climate). This calculation is made for each season of the year. The results obtained from this simple analysis are shown in figures 1.20 and 1.21 by means of isolines superimposed over the spatial distributions of the increases in mean seasonal temperatures and rainfall.

This figure shows that the monthly variability in projected mean temperatures for the last third of the century is generally greater than that of the present simulated climate, with positive percentages of around 20% or below. Some differences can be appreciated, however, between the two emission scenarios considered. Thus, in B2 the percentages of change in temperature variability are lower than in A2. With regard to distribution according to seasons, the biggest changes are observed in summer and the smallest in autumn. However, the spatial and seasonal distribution of the percentages of changes in temperature variability is not regular over the Peninsula. Scenario A2 presents increases of over 20% in the periphery of the Peninsula in summer, whereas in the Northeast there is hardly any alteration in autumn. In scenario B2, however, few changes are observed in variability in autumn, and those in summer are much smaller than in scenario A2, more similar to those observed in winter and spring. Furthermore, in the Canary Isles, the percentages of change in variability are similar in the four seasons and the two scenarios, with values of around 20%, except in scenario A2 in winter, when values of 40% are reached. These increases in temperature variability would mean that the monthly thermal anomalies in the climate projected for the end of the century will tend to be more intense than in the present climate. Figure 1.24 provides an outline of the qualitative change that the distribution of frequencies of mean temperatures in the future climate would undergo in comparison with the present, according to the simulated climate change results. From this figure, we can deduce that in the extremely hot months, the rise in temperatures in the future climate will be somewhat greater than the values of the increase projected for the mean temperatures of the present climate. The magnitudes of this percentage would be the values indicated.

With regard to the change in the interannual variability of rainfall, applying the same simple procedure as the one used for temperatures, no appreciable changes were observed in any season of the year (figure 1.21). Increases of around 20% only appear in the Northeast of the Iberian Peninsula during winter. These results appear to indicate that the frequency of anomalies in the monthly or seasonal rainfall of the projected climate for the last third of the 21st century would be similar to that of the present climate. However, the application of the simple statistical method used is questionable in the case of rainfall because its frequency distribution does not adjust to a Gaussian type curve, as it mostly occurs with temperatures. For a more correct analysis of the possible alteration in rainfall variability, we would have to consider the frequency of daily extreme events, including rainfall intensity (IPCC 2001). An analysis in this respect will subsequently be presented.

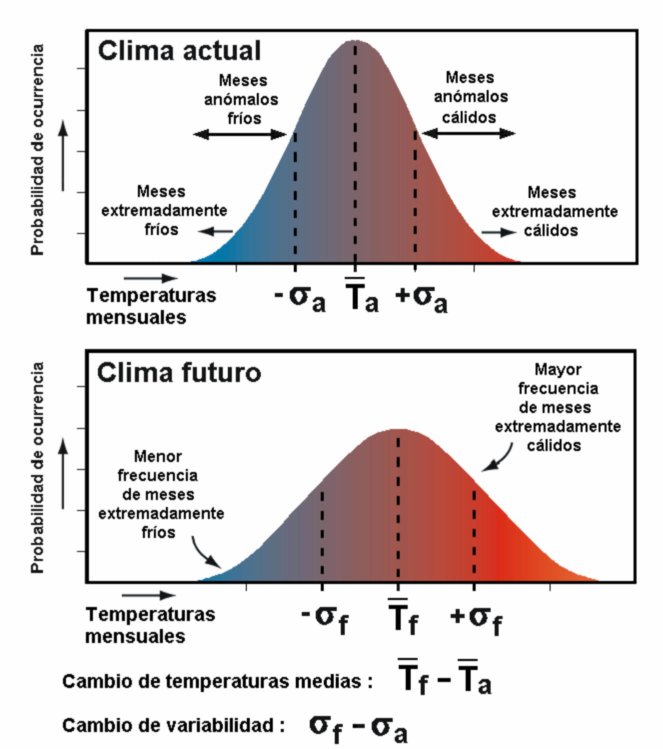

Fig. 1.24. *Illustration of the distributions of frequency of monthly temperatures in the present climate and in the projected climate.*

It must be mentioned, however, that the interannual variability that an AOGCM can simulate depends to a great extent on the way in which it models atmosphere-ocean interactions. Thus, although most AOGCMs seem to be able to project increases in interannual variability in scenarios of disturbed climates, others present contradictory results (page 362 of the IPCC report 2001). Which means to say that there is still great uncertainty regarding the possible alteration of low-frequency variability in future climate scenarios. Consequently, as the interannual variability simulated by any regional climate model is closely linked to the information provided by the AOGCM in which it is nested, the previous results should be considered with due caution.

A study complementing the one on alteration of low-frequency climate variability is the one relating to the possible changes in the so-called climate extremes. Values of atmospheric variable that are very distant from the climatological averages, occurring in exceptional meteorological conditions, are understood as climatic extremes. The interest aroused by this other type of study lies in the fact that it is believed that the impacts of future climate changes due to changes in climate extremes will probably be more severe than those related to average climate changes. Although these events are relatively infrequent, they can have a great impact on the environment or on human health. There are many possible criteria or indices for characterising extreme climatic events. The most used ones are chosen because of the availability of the variables required for calculating them, the ease with which they are interpreted and their applicability to impact studies, and also because they allow for an objective and complete description of the frequency and intensity of climatic extremes.

Of the wide range of indices of climatic extremes applicable to temperatures, we could consider those based on percentiles. Thus, as Jones *et al.* (1999) showed, in order to characterise the intensity of extremely hot or cold temperature conditions, we would have to use, respectively, 90 percentile of the distribution of maximum daily temperatures (hereinafter $T_{max}90$) and 10 percentile of the distribution of minimum daily temperatures (hereinafter $T_{min}10$). Using the simulations with the RCM PROMES these intensity indexes of daily thermal extremes were calculated for each one of the two 30-year periods (1961-1990 and 2071-2100) and each season of the year. The differences between the values corresponding to emission scenario A2 and the control experiment (present climate) are now presented. These differences between percentiles are expressed in ºC.

The biggest changes in $T_{max}90$ are observed in summer and spring in the inland area of the Peninsula, reaching values of 7ºC. In winter the differences are smaller, not reaching 5ºC. The spatial distributions of the changes in $T_{max}90$ are very similar to those of the average changes in maximum daily temperatures (hereinafter T_{max}), but the same is not so for the values. The changes projected for $T_{max}90$ are generally greater than for T_{max}, except inland on the Peninsula in summer, where the latter ones surpass the former ones by a few tenths of a degree. What is most noteworthy, however, are the changes $T_{max}90$ obtained in spring, above all, and in autumn, as they are clearly bigger than the changes in T_{max} (figure 1.25). Thus, it can be seen that in spring, the changes in $T_{max}90$ reach 7ºC whereas the changes in T_{max} are around 2ºC lower in most of the Peninsula. In autumn, however, these differences remain at around 1ºC lower, although in the North and Northeast of the Peninsula, they reach 2ºC.

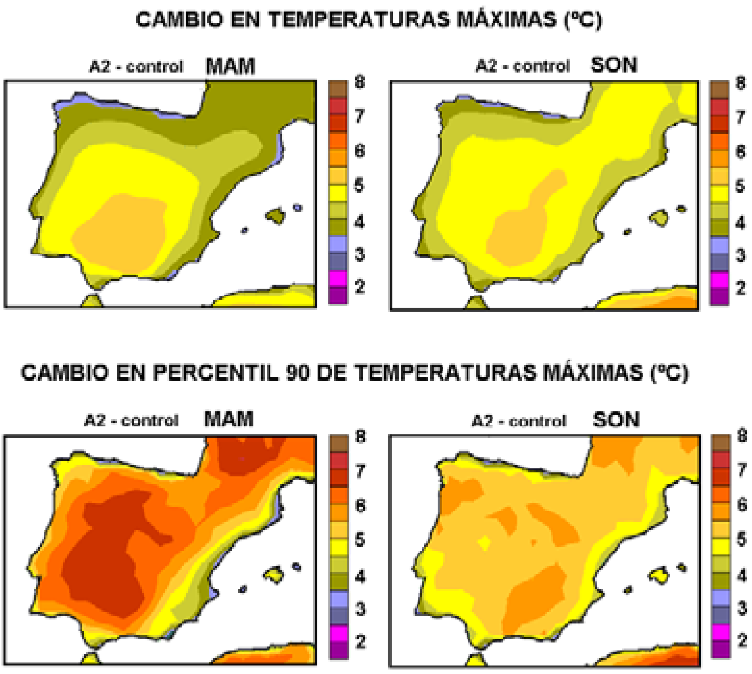

Fig. 1.25. *Differences in seasonal averages of daily maximum temperatures (above) and in 90th percentiles (below) between the simulation with A2(2071-2100) emission scenarios and the control one (1961-1990) corresponding to spring (MAM) and autumn (SON).*

For a correct interpretation of this different seasonal behaviour in the changes projected for T_{max} and $T_{max}90$, perhaps a more detailed statistical analysis of these changes would be needed. This result, however, could be an indication that in the climate projected for 2071-2100 there is a greater frequency of extremely hot days at the end of spring and the beginning of autumn, compared to the present climate. We must keep in mind that both T_{max} and $T_{max}90$ were calculated for each season considering the days included in three-month: December – February for winter, March – May for spring, June – August for summer and September – November for autumn. The bigger increase of $T_{max}90$ in relation to that of T_{max} in spring could therefore be in accordance with the fact that the warming projected for the month of May is greater than what corresponds to April and is more similar to that of the summer months. A similar explanation could be applied to the projections for autumn, because the increase in T_{max} in September is also bigger than in the other months of autumn. In the results of projections of climate extremes at the end of this century for emission scenario SRES-A2 obtained by Sánchez *et al*. (2004) an increase in the frequency of heat waves in spring and autumn can be appreciated, and this seems to be in consonance with what was previously established. Shär *et al*. (2004) and Beniston (2004) coincide in an increase in summer heat waves in Europe in future climate scenarios.

With regard to the changes projected in $T_{min}10$, a very similar behaviour to that obtained for T_{min} is observed. But once again it can be seen that the increases in $T_{min}10$ are somewhat smaller than those in T_{min} in spring and autumn on most of the Iberian Peninsula. The same thing occurs in the summer months in the North of the Peninsula, but not in the rest of the territory. However, the differences between the increases in $T_{min}10$ and in T_{min} do not generally exceed a value of 1 degree. Which means to say, that they are smaller than those mentioned in the case of $T_{max}90$ and T_{max}. Using the previous reasoning, it could be speculated that the fact that the changes projected for $T_{min}10$ are smaller than for T_{min} might be an indication that in the climate in the last third of the century, there would be less frequency of extremely cold days. However, the results of Sánchez *et al*. (2004) indicate a higher frequency of cold spells, but this might possibly be due to criteria considered by these authors to define the occurrence of these extreme events.

We now include a brief analysis of the changes projected for daily rainfall extremes in the emission scenario SRES-A2, in comparison with the simulation of the present climate. In order to characterise the intensity and frequency of these extreme events, different criteria can be considered (Jones *et al*. 1999). In this case, one of these was selected: Number of days with accumulated rainfall, of over 1 mm for each season of the year, averaged over a period of 30 years. Hereinafter, this index will be know as NPr1.

For each one of the two 30-year periods considered (1961-1990 control and 2071-2100 scenario) we calculated the seasonal averages of NPr1 and the differences between the values corresponding to scenario SRES-A2 and to the control experiment (present climate). The differences were calculated as a percentage in relation to the values simulated in the control experiment (present climate). On expressing the differences in percentage, the numerical results thus obtained should coincide with those that would be obtained considering any percentage of the distributions of daily rainfall. Thus, for example, as the number of days with rainfall corresponding to the 90th percentile (indicated by NPr90) is by definition the total number of days with rainfall (NPr1), then the percentage change of NPr90 between the two experiments of scenario and control would be equal to the percentage change of NPr1:

$$\frac{N\,Pr\,90\,(A2)-N\,Pr\,90\,(control)}{N\,Pr\,90\,(control)}=\frac{0.1\cdot N\,Pr\,1(A2)-0.1\cdot N\,Pr\,1(control)}{0.1\cdot N\,Pr\,1(control)}=\frac{N\,Pr\,1(A2)-N\,Pr\,1(control)}{N\,Pr\,1(control)}$$

Figure 1.26 shows the distributions of the changes in NPr1 projected for the Iberian Peninsula for each season of the year. Therein, it can be seen that in spring and summer, the changes in NPr1 have a negative sign, that is, a lower number of rainy days, throughout the whole Peninsula. In summer, values of percentage differences for Npr1 are not seen in the southernmost part of the Peninsula, because in the control experiment (1961-1990) NPr1 is very small (< 10 days),which gives rise to unrealistic change percentages.

The negative changes in NPr1 might be related to the greater persistence and duration of the periods of rainless days in the scenario of disturbed climate, than in the present one. However, in winter, an increase of over 10% in the NPr1 can be observed in the Northeast of the

Peninsula, and the same can be observed in autumn in the Northeast and the Levant. The regions and time of year in which these positive changes in NPr1 are simulated essentially coincide with those of increases in accumulated rainfall shown in figure 1.21. Sánchez *et al*. (2004) present results of changes in rainfall extremes simulated for the disturbed climate scenario, considering an intensity index of extreme rainfall (percentile 90) encompassing the whole Mediterranean region. These authors show that changes in the torrentiality of rainfall on the Peninsula present a high spatial variability in all the seasons of the year. This could be related to the fact that simulated extreme rainfall shows a high degree of uncertainty. Likewise, Christensen and Christensen (2003) present results of regional climate simulations for the end of the 21st century, in which an increase can be seen in torrential rains during the summer months in Europe, although this result presents a high degree of uncertainty for the Iberian Peninsula. A possible procedure for reducing these levels of uncertainty could be by analysing the complete set of simulations made by the regional climate models used in the European project PRUDENCE.

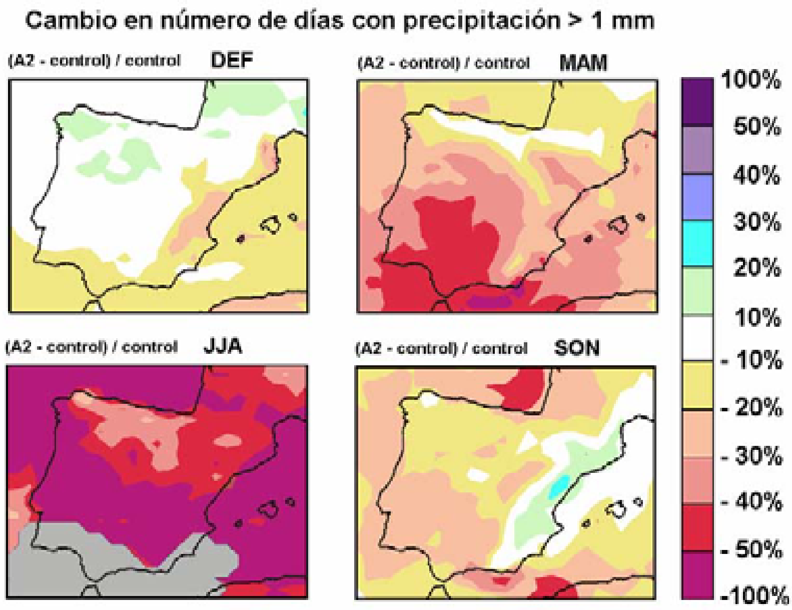

Fig. 1.26. *Changes in the number of days with precipitation over 1 mm between the simulation of A2 (2071-2100) emission scenarios and the control one (1961-1990), expressed in percentages in relation to the present simulated climate, corresponding to each season of the year (DJF winter, MAM spring, JJA summer and SON autumn). The grey colour in the summer figure indicates that in those regions there is too little precipitation in the control experiment.*

1.3.6. Conclusions

In order to analyse disturbance of Spain's climate possibly deriving from global climate change due to the accumulation of GHGs throughout the 21st century, the results were used of a set of climate simulation models. In this analysis, six global models (AOGCM) were considered, along with a regional model. The results obtained with them are not climatic predictions, but rather projections of how future climate could be altered, taking current climate characteristics (1961-1990 period) as a reference. Also taken into account were two possible scenarios of global emissions of GHGs and aerosols, designed by the Inter-governmental panel of experts for the study of Climate Change (IPCC), based on demographic, social and economic criteria. These scenarios, known by the abbreviations SRES-A2 and SRES-B2, are the two that have been most used to date to make projections of climate change.

In the results of the climate scenarios made by the six AOGCMs considered, there are discrepancies regarding the magnitude of the changes projected in relation to temperatures and to the total amounts of rainfall in Spain in the 21st century, although notable qualitative coincidences can also be seen. The most significant results obtained can be summarised as following:

a) The models coincide in that the growing tendency of mean temperatures present a regular behaviour pattern throughout the century, although this warming is more accentuated in emission scenario SRES-A2 than in SRES-B2.
b) The models coincide in that the temperature increase projected throughout the century is more intense in summer than in winter, and reaches intermediate values in the other two seasons of the year.
c) Taking the average of the set of six AOGCMs, in emission scenario SRES-A2 the average tendency of temperature over the century varies by approximately 1.2ºC every 30 years in winter and by 2ºC every 30 years on the Iberian Peninsula.
d) In emission scenario SRES-B2 these mean temperature increases reach an approximate value of 1.1ºC every 30 years in winter and 1.8ºC in summer.
e) The six AOGCM coincide in projecting a significant decrease in total annual rainfall over the Iberian Peninsula, which is somewhat more intense in scenario A2 than in B2.
f) This decrease tends to be bigger in spring and smaller in winter.
g) The tendencies of change in seasonal rainfall are not generally uniform throughout the century, although there are notable discrepancies between models. Some models project more accentuated decreases in rainfall in some seasons of the year up to the middle third of the 21st century, and other simulate more uniformly progressive decreases throughout the century.

The discrepancies observed in the climate changes projected for the Iberian Peninsula by the different AOGCMs are fundamentally considered to be related to the different spatial resolutions used by each one (cell sizes between 600 and 250 km) and to the different degree of complexity of the parametrisation schemes of atmospheric and oceanic processes that they use. For this reason, an analysis has been made of the changes projected for future climate on the Iberian Peninsula, considering the results obtained by one of the six AOGCMs, that uses a relatively high resolution (more spatial detail) and which uses a more complete and updated set of physical parametrisations. This is the case of the model HadCM3 developed in the Hadley Centre for Climate Research in the United Kingdom.

Th results of the projected changes in mean temperature and rainfall obtained with the global model HadCM3 allow for a certain spatial discrimination over the Iberian Peninsula. As an outline, the most relevant conclusions of the projected climate changes in Spain obtained using the aforementioned global model are:

a) The smallest temperature increases are obtained in the Northeast of the Peninsula and the biggest ones in the South.
b) The greater upward tendency of temperatures throughout the century corresponds to the summer months and the smaller one to winter, both of these more accentuated in emission scenario A2 than in B2.
c) In the projections of change in rainfall, generalised decreases are obtained in annual values, which are higher in scenario A2 than in B2, but the spatial and seasonal distributions of these are not uniform in Spain.
d) For the last third of the 21st century, an increase in winter rainfall is projected in most of the territory, and in autumn a slight increase in the Northeast of the Peninsula, whereas it is in spring and summer when the biggest generalised decreases are obtained.
e) The absolute values of change in seasonal rainfall reach lower values in the intermediate periods than in the last third of the century, although generally maintaining the sign of the changes projected for the end of the century.
f) The downward tendencies in rainfall are more accentuated in emission scenario A2, whereas the upward ones are somewhat greater in scenario B2.

In order for the results of climate change projections to have greater spatial resolution, the regional climate model PROMES was used, nested in the global model HadAM3. The cell size of the regional model is 50 km, which allows for a more suitable reproduction of the orographic features of the Peninsula and also to allow the bigger islands of the Balearic and Canary Isles to be considered. Indeed, it has been seen that the PROMES model provides a more satisfactory reproduction than the global model of the climatological distributions of temperature and rainfall over Spain. This would seem to indicate that the projections of future climate obtained with the PROMES model are more appropriate for analysing impacts at regional scale than those derived directly from the global model.

The projections of climate change made with the regional model only correspond to the last third of the 21st century (2071-2100), and they were deduced taking as a reference the climate simulated by this model in the 1961-1990 period (control experiment). Likewise, the two GHG emission scenarios were considered (A2 and B2). The results presented correspond to mean temperature (in ºC), rainfall (in mm), amount of water evapotranspired (in kg · m^{-2}) and wind speed (in m · s^{-1}). A summarised outline is now presented of the most relevant projections for each variable, each season of the year and each emission scenario, with a discrimination of the different regions of Spain to the extent permitted by the resolution of the model.

a) Changes in mean temperatures:

Season	Scenario	Changes projected for the 2071-2100 period compared with 1961-1990
Winter	**A2**	Increases of between 2 and 3ºC in the west and north of the Peninsula and the Canary Isles, and of between 3 and 4ºC in the rest of the territory
	B2	Distribution of warming similar to that of scenario A2, but 1ºC less intense
Spring	**A2**	Increases of between 4 and 5ºC in the south-west of the Peninsula, of between 2 and 3ºC on the Cantabrian fringe, northern Galicia and Canaries, and of between 3 and 4ºC in the rest of the territory
	B2	Increases of between 1 and 2ºC in the Canary Isles, Cantabrian fringe and northern Galicia, and of between 2 and 3ºC in the rest of the territory
Summer	**A2**	Increases of between 5 and 7ºC inland on the Peninsula, of between 4 and 5ºC close to coastal zones on the Peninsula and the Balearic Isles and of between 2 and 3ºC in the Canary Isles.
	B2	Distribution of warming similar to that of scenario A2, but generally 1ºC less intense
Autumn	**A2**	Increases of between 2 and 3ºC in the Canary Isles, of between 3 and 4ºC in the northern third of the Peninsula and of between 4 and 5ºC in the rest of the territory
	B2	Distribution of warming similar to that of scenario A2, but generally 1ºC less intense

b) Changes in accumulated precipitation:

Season	Scenario	Changes projected for the 2071-2100 period compared with 1961-1990
Winter	**A2**	Increases by over 10 mm in the north-eastern quadrant of the Peninsula, decreases by over 10 mm in the southern third and the peninsula Mediterranean regions, without any appreciable changes (±10 mm) in the rest of the territory
	B2	Increases by over 10 mm in northern Galicia and without any appreciable changes (±10 mm) in the rest of the territory
Spring	**A2**	Decreases by over 20 mm in practically all of the Peninsula, without any appreciable changes (±10 mm) in the Balearic and Canary Isles
	B2	Decreases by over 10 mm in practically all of the Peninsula, without any appreciable changes (±10 mm) in the Balearic and Canary Isles
Summer	**A2**	Decreases by over 40 mm in northern Galicia, Cantabrian fringe, Pyrenees and Northeast of the Peninsula, decreases by between 10 and 40 mm in the rest of the territory, except in the Canary Isles, without any appreciable changes (±10 mm)
	B2	Distribution of the changes in seasonal rainfall similar to that of scenario A2
Autumn	**A2**	Increases by over 10 mm in the Northeast of the Peninsula, decreases by over 20 mm in the south-western half, without any appreciable changes (±10 mm) in the rest of the territory
	B2	Distribution of changes similar to that of scenario A2, although somewhat less intense in the south-western half of the Peninsula

c) Changes in evapotranspiration (en %)

Season	Scenario	Changes projected for the 2071-2100 period compared with 1961-1990
Winter	**A2**	Increases by less than 20% in practically the whole territory
	B2	Increases by less than 20% in practically the whole territory
Spring	**A2**	Increases by over 20% in most of the north-eastern quadrant of the peninsula and the Pyrenees, increases by less than 20% in the rest of the northern half, and decreases by less than 20% in the rest of the territory
	B2	Increases by over 20% in Galicia, and less than 20% in practically the rest of the territory
Summer	**A2**	Decreases by over 20% in the southern third of the Peninsula, by less than 20% in the centre and the Balearic Isles, and increases by less than 20% in the northern third of the Peninsula
	B2	Distribution of the changes similar to that of scenario A2, but less intense in the southern third of the Peninsula
Autumn	**A2**	Increases by less than 20% in the northern third of the Peninsula and the north of the Levant/Mediterranean coast, decreases by over 20% in the southern third of the Peninsula and decreases by less than 20% in the rest of the territory
	B2	Distribution of changes in evapotranspiration similar to that of scenario A2

d) Changes in wind intensity (in %)

Season	Scenario	Changes projected for the 2071-2100 period compared with 1961-1990
Winter	**A2**	Decreases by over 5% in the southern half of the Peninsula and the Balearic Isles, increases by over 5% in the Canary Isles, without any appreciable changes (± 5%) in the rest of the territory
	B2	Increases by over 5% in the Canary Isles, without any appreciable changes (± 5%) in most of the rest of the territory en la mayor
Spring	**A2**	Increases by over 5% in the Canary Isles and in the Gibraltar Straits, decreases by over 5% in the Cantabrian fringe, inland Levant and the Balearic Isles, without appreciable changes (± 5%) in the rest of the territory
	B2	Without appreciable changes (± 5%) in the whole territory
Summer	**A2**	Increases by over 5% in the centre and Southeast of the Peninsula, without appreciable changes (± 5%) in most of the rest of the territory
	B2	Decreases by over 5% in most of the Peninsula and the Balearic Isles, without appreciable changes (± 5%) in the southern third of the peninsula and the Canary isles
Autumn	**A2**	Decreases by over 10% in the Cantabrian fringe Northeast and the Eastern Peninsula, decreases by between 5 and 10% in the rest of the territory, except in the southern third of the Peninsula and the Canary Isles, where there are no appreciable changes (± 5%)
	B2	Decreases by over 5% in the north-eastern quadrant of the Peninsula, Cantabrian fringe and the Balearic Isles, without any appreciable changes (± 5%) in the rest of the territory

As a compliment to the analysis of the changes projected for the mean values of climatic variables, we have also included an initial approach to a possible alteration of the interannual variability of monthly values in the last third of the century (2071-2100) in relation to that of the 1961-1990 period. The most relevant results of this analysis can be summarised in the following points:

a) An increase is projected in the range and frequency of monthly thermal anomalies in the future climate in comparison to the present one.
b) Although this increase cannot be seen in a regular manner throughout the whole territory, the increases in range remain at around 20% in all the seasons of the year and in both emission scenarios. This means that in the anomalous hottest months in the future climate, the temperature increases will be around 20% higher than the projected values for average warming.

c) The percentages of change in the variability of monthly temperatures are somewhat lower in the B2 scenario than in A2, the same as what occurs with the magnitudes of average warming.
d) No significant alterations can be found in the frequency of anomalies in monthly rainfall in the future climate scenarios considered, although this conclusion is questionable, because the statistical method used is not the most suitable one for this type of analysis.

Finally, an analysis has been included of possible alterations of the occurrence of extreme climatic events in the future climate scenarios, in comparison with the present climate. To this end, we considered the values of extreme percentiles of the daily distributions of maximum and minimum temperature, as well as the frequency of days with rainfall higher than 1 mm. In this case, only the results of emission scenario A2 were considered. The most relevant conclusions can be summarised as:

a) The frequency of days with extreme maximum temperatures on the Iberian Peninsula tends to increase very significantly in spring and to a lesser degree in autumn, whereas in the Balearic and Canary Isles, no appreciable changes have been observed, as occurs in the other two seasons of the year throughout the whole territory.
b) The frequency of days with extreme minimum temperatures on the Peninsula tends to decrease.
c) The persistence and duration of periods of rainless days generally tend to decrease in the same zones and seasons for which negative changes are projected in seasonal rainfall, an to increase in the cases in which increases in rainfall are simulated in the future climate, compared to the present one. Although this analysis appears to indicate that would be no significant change in the degree of torrentiality of rainfall in the projected climate, this result presents a high degree of uncertainty.

By way of a conclusion, the following table provides an outline of the most relevant projections of climate change in Spain, arranged according to the degree of certainty provided by the results of the simulations by the set of models considered. To this end, we considered the degree of consensus among the different climate models available, so that the highest degree of certainty is assigned to those changes in which all the models coincide, the degree of certainty decreasing along with a decrease in the number of coinciding models. The lowest degree of certainty corresponds to the situation in which only a minority group of models provides similar results.

Table 1.4. *Level of uncertainty of the most relevant climate changes projected for Spain*

Certainty	Most relevant climate changes projected for Spain
*****	Progressive upward trend of mean temperatures throughout the century
*****	The warming tendency is more evident in the scenario of more accelerated emissions (SRES-A2)
*****	The increases in mean temperature are significantly greater in the summer months than in winter, with intermediate values in the others.
****	Warming in summer is greater in the inland areas than close to the coast or on the islands
****	Generalised tendency towards less accumulated annual rainfall in both emission scenarios throughout the century
***	Greater range and frequency of monthly thermal anomalies related to the present climate
***	More frequency of days with extreme temperatures on the Peninsula, especially in summer
***	The biggest decrease in rainfall on the Peninsula is projected in the spring months in both emission scenarios
**	Increased rainfall in the West of the Peninsula in winter and in the Northeast in autumn.
**	Changes in rainfall tend to be more significant in the scenario of more accelerated emissions (SRES-A2)

(***** very high certainty, **** high certainty, *** medium certainty, ** low certainty)

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2. IMPACTS ON TERRESTRIAL ECOSYSTEMS

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ABSTRACT

Spain presents a large variety of terrestrial ecosystems, many of them unique, and all of them offering a wide range of goods and services. These ecosystems have been subjected to intense climate change in the past, but the rhythm of these changes has accelerated in an exceptional manner as a consequence of the anthropogenic emission of greenhouse gases. Accelerated climate change is bringing about a series of direct and indirect effects which are accentuated by the interaction with other motors of global change (changes in land use, pollution, biotic exchange). The effects are different for the ecosystems of the Atlantic region, limited by temperature, and for those of the Mediterranean region, limited by water. Whereas productivity could increase with climate change in the former, it might possibly be reduced in the latter.

The ecosystems that are at their ecological or geographic limit (formations with zero water balance, ecosystems dominated by relic species from past climates, high-mountain ecosystems, certain formations in arid regions) are the ones that will be most affected by climatic change.

The areas and systems most vulnerable to climate change are islands in the broad sense (including edaphic islands and high-mountain ecosystems) and ecotones or transition zones between systems. The spatial situation of the latter could be used as an integrated indicator and as a possible early warning of climate change.

There is scientific evidence that climate change will affect the phenology and interactions between species, favour the expansion of invading species and pests, will cause changes in the dominance, structure and composition of the communities, and will increase the impact of disturbances such as fire. With climatic change, the capacity for sequestration of atmospheric carbon of the ecosystems will decrease and altitudinal and latitudinal migrations of species will occur, along with the extinction of local species.

However, it is currently unknown whether species will be capable of evolving and adapting to climate change in time, whether plants will increase their efficiency with regard to water use in times of drought and warming, and whether these processes will accelerate the biogeochemical processes.

The management of terrestrial ecosystems should involve society as a whole and ought to seek creative formulae for the funding of activities for the mitigation of effects, restoration and research. The conservation of terrestrial ecosystems in a scenario of climate change clashes with numerous human activities, especially in relation to the use of natural resources like water. This conservation is at odds with management aimed at maximising production or at sequestrating atmospheric carbon.

Noteworthy among the main research needs is the consolidation of long-term ecological follow-up networks, making as much use as possible of the existing ones and favouring the interdisciplinary participation of the scientific community, the study of interactions, both between environmental factors and between species and trophic levels, along with the determination of minimum tolerance levels (climatic, structural, functional) in systems vulnerable to climatic change.

2.1. INTRODUCTION

2.1.1. Human influence in terrestrial ecosystems: the multiple effects of a spreading species

At an increasingly faster rate, humans are modifying the spatial distribution and functioning of ecosystems. This modification is occurring at local, regional and global scale so that, currently, the vast majority of ecosystems present a certain degree of degradation or alteration attributable to human activities (Vitousek *et al.* 1997). Furthermore, these activities are changing the biophysical properties of the atmosphere and of the climate, and there is irrefutable proof that the ecosystems are responding to all these changes (Hulme *et al.* 1999, Hughes 2000). Although much of this proof is based on the responses of particularly sensitive species, there are more and more results that show effects at the level of the whole ecosystem. Although these effects are not easily appreciable, they generally have a temporal time scale of several decades and are frequently influenced by local conditions (Vitousek *et al.* 1997, Parmesan and Yohe 2003).

2.1.2. The diversity of Spanish terrestrial ecosystems

Very much due to its geographical position and complex orography, Spain presents a great variety of terrestrial ecosystems, one of the widest in Europe. Of the six biogeographical regions contemplated in the Directive Habitats, four are represented in Spain (the Atlantic, Mediterranean, Alpine and Macaronesian) encompassing 141 different types of terrestrial habitats from a total of 264. This extraordinary variety of terrestrial ecosystems together with the particular evolutionary history of Spain, has given rise to a great diversity of species, natural resources and unique biological systems, which have led to the protection of 536 natural spaces throughout the country. Approximately 20% of the country's 50 million hectares (Mha) corresponds to forest ecosystems in the broad sense (the figures oscillate depending on the definition of forest ecosystem). The Mediterranean region is the largest, with 43 Mha, of which 3 Mha are forests, 2.9 Mha are shrubland and heathlands, and 2.6 Mha are natural or semi-natural pastures. The Atlantic region takes up 5.5 Mha, including 1.1 Mha of shrubland and heathlands, and 0.5 Mha of forests. The Alpine region occupies 0.9 Mha and is dominated by natural and seminatural pastures (0.2 Mha) and by forests (0.2 Mha). The smallest region is the Macaronesian (0.7 Mha) and here, forests and shrubland total 0.1 Mha (Reyero 2002). Apart from climatic and biogeographic features, the degree and temporal extent of human intervention are other intrinsic characteristics that must be taken very much into account in the description of Spanish terrestrial ecosystems. The human intervention varies from intense and prolonged in the Mediterranean and Atlantic regions to moderate and relatively more recent in the Alpine and Macaronesian regions. The surface area of the Spanish Mediterranean region represents 17.3% of the whole Mediterranean region in the strict sense, which is distributed throughout 18 countries, and is only surpassed by Turkey (20.8% of the total).

Thus, Spanish terrestrial ecosystems are exposed to a great natural climatic variability, and are the result of a noteworthy topographic and lithological complexity and marked gradients in land uses and in water availability, and frequently accommodate a high level of biodiversity. As we will see, these and other characteristics make many of these ecosystems particularly sensitive to atmospheric and climatic changes. An understanding of the effects of climate change on terrestrial ecosystems is crucial in order to take the measures necessary to guarantee the multiple goods and services they provide us with, many of which are vital to our very existence.

2.1.3. Goods and services of the terrestrial ecosystems

From the anthropocentric point of view, terrestrial ecosystems are systems that fulfil three general types of functions: productive, environmental and social (Rodá *et al.* 2003). In their productive function, they provide renewable natural goods, such as food, medicines, timber products and non-timber products (pastures, cork, pine cones, game, fungi, etc.). Among the environmental and ecological functions are the ecosystem services provided free of charge, like the maintenance of biodiversity, regulation of atmospheric composition and of the climate, the regulation of biogeochemical cycles, soil conservation (e.g. prevention of erosion), the regulation of the water cycle and of carbon storage. Among the social functions, the most important ones are recreation, education and leisure uses, demonstrated health benefits, opportunities for research, the traditional cultural and emotional values, and functioning giving rise to important economic activities like tourism and hiking. It is clear that the alterations caused by atmospheric and climatic changes will have an impact on many of these goods and services, and consequently, an impact on the socioeconomic systems (Winnet 1998). Among the ecosystem functions and services, we can highlight atmospheric carbon sequestration and storage, because this is the basis of the plant production that sustains the ecosystems and because it has direct implications in the balance of atmospheric CO_2, one of the main agents of climatic change. Other ecosystem services include the provision of pollinators and pest control.

Terrestrial ecosystems are considered to be important regulators of both global and local climate, decisively influencing biogeochemical cycles and characteristics of the atmosphere. Certain terrestrial ecosystems like forests affect relative humidity and even local rainfall regimes, and can give rise to a feedback cycle in which the forest favours hydric conditions in order to maintain itself. Although it has been established on numerous occasions that when vegetation cover is high (when the leaf area index – LAI – increases), there is less water available in the ecosystem due to an increase in transpiration (Rambal and Debussche 1995), the forest can serve to capture water in certain Mediterranean conditions. Experimental data and numerical simulations indicate that the presence of tree masses on coastal mountain slopes significantly favours the formation of summer storms and the collection of water which, in the form of more or less dense fog, rises from the sea (Millán 2002). Although these local effects of the forest on microclimate and rainfall are evident and have been proven, their influence on regional climate (macroclimate) is less clear. In simulations of the effects of extensive deforestation in Spain and France, it has been found that the forest only favours rains when these occur in summer by means of vertically developed clouds, in whose formation forest transpiration can actively intervene (Gaertner *et al.* 2001).

2.1.4. Human impact on Spanish ecosystems

Intense human intervention is a characteristic typical of most Spanish terrestrial ecosystems. These ecosystems have been very much modified by man from the start of the Neolithic, specially since the Bronze Age, causing a general reduction of their original forest surface areas (Pons and Suc 1980, Reille and Pons 1992). Within this process of intervention, certain qualitatively new semi-natural and relatively stable ecosystems have been created, such as the *dehesas* of species of *Quercus* (Stevenson and Harrison 1992). Anthropic action over the last few millennia is a critical element that has determined radical changes in diversity and in tree and shrub cover, and, in short, in the structure and functioning of many terrestrial ecosystems. Carrión *et al*. (2003) reconstructed the history of the vegetation in the Sierra de Gádor mountain range in the Southeast of the Iberian Peninsula using a palaeo-ecological register. They showed significant changes in the abundance of plant species, with the replacement in dominance of deciduous *Quercus* by evergreen *Pinus* and *Quercus* around 3940 years BP, the maximum rise of *Pinus* to the detriment of the evergreen *Quercus* between 1760-1629 years BP, along with the diminished size of the forests accompanied by an increase in helophytes until 1160 years BP. Among the factors that resulted in vegetation change during the second half of the Holocene are the occurrence and frequency of fires, human activity, climate change and the interrelation between these. Since that time, climate and human activity have become inextricably interrelated.

Within a more recent temporal framework, in Spain at the beginning of the 20th century, large reforestation programmes were started for production purposes, which coincided with the rural crisis throughout the western world and the abandonment of the countryside, which was re-colonised by communities of woody plants. The abandonment of crops on poor soils, a common practice on the Iberian Peninsula, has led to a marked change in the structure and functioning of the ecosystems, with an increase in floristic and faunistic diversity, an improvement in the quality of the soil and of the hydrological cycle and reduced soil erosion. But the abandonment of many traditional practices also leads to the crisis of production systems of great natural value due to their high biodiversity, such as the *dehesa*, and to the ageing of the underwood containing species of *Quercus*, which, on not being managed lose vigour and become more sensitive to abiotic disturbances (drought and climatic extremes) and biotic ones (pests and diseases). In turn, the accumulation of biomass favours fires. The general forest area increased in the last third of the 20th century and there has been a rise in the number of protected natural spaces, resulting from the spread of an ecological vision of the forest and of terrestrial habitats. The natural recovery is observed of Holm oak forests and Cork oak forests in less dry, sub-Mediterranean marginal areas, but there is an increase in the environmental deterioration of the air and the waters, and in the rhythm of climatic change. There is little protection of natural spaces outside the mountainous areas or historic or emblematic sites, and the forests, shrublands and pastures become fragmented and disconnected (Costa *et al.* 1990, Valladares 2004a). Likewise, there are areas (certain abandoned crop fields, stipa-dominated grasslands) and shrublands affected by overgrazing) in which, in spite of the abandonment of traditional practices, the degree of degradation, combined with unfavourable climatic cycles, has considerably hindered the spontaneous recovery of the vegetation.

2.1.5. Changes in the carbon balance, cause and consequence of climate change

The carbon balance of terrestrial ecosystems is the result of processes that trap atmospheric CO_2 (e.g. photosynthesis) and processes that release CO_2 (e.g. respiration, fires). A vital aspect at the present time is to determine to what extent terrestrial ecosystems can act as carbon sinks thus attenuating global warming. But to make a detailed calculation of the carbon balance is not an easy task, especially when different scales of time and space intervene in the analysis. There is great uncertainty regarding how these affect the environmental conditions interacting with the diverse processes involved. Furthermore, in order to understand carbon flows, it is important to quantify the amounts of carbon existing in our ecosystems. For the aerial part, good databases are available, like those provided by forest inventories, although there is a lack of data on ecosystems not included in this initiative. The least known part corresponds to subterranean biomass, which is considerable in Mediterranean ecosystems and, in the case of a Holm oak forest, can account for 50 per cent of total biomass. To this carbon we must add the necromass accumulated on the ground, which frequently exceeds the total carbon of the biomass, although very little information is available in this respect.

Analyses based on national forest inventories reveal that, for much of the 20th century, Spanish forests have acted as carbon sinks and that all the Spanish regional autonomies accumulated carbon in their forests during the 1974-1987 period (Rodríguez-Murillo 1997, Rodríguez-Murillo 1999). This accumulation oscillated from 4.5 tons of carbon per hectare and year in Galicia (2.0 in the previous period) to 1.1 in Murcia (0.27 in the previous period). This effect is attributed to the reforestation carried out in the 1940's and to the most recent changes in agriculture and livestock farming uses which have contributed to the increase in tree cover and in the density of the forest masses (Rodríguez-Murillo 1999). With regard to the emission of greenhouse gasses (CO_2, CH_4, N_2O) from forest fires in the 1970-2001 period, the average value is $21.5*10^6$ tons for the whole country for direct emissions; delayed emissions are, on average, 3.8 time higher than these (Prieto and Rodríguez-Murillo 2003). Galicia was the regional autonomy that most contributed to the total emissions of greenhouse gasses as a consequence of forest fires. However, it must be pointed out that the data on the total estimated emissions of CO_2 only represent 1% of the total estimated emissions of this gas for Spain.

2.1.6. Methods of study of the effects of climate change

The study of the effects of climate change on our terrestrial ecosystems was carried out using five types of activities covering different time scales: (1) the palaeoecological study of datable sedimentary cores, with the use of biological and geochemical indicators (thousands of millions of years), (2) the study of different types of historic material, like, for example, specimens of herbarium, museum pieces, archives, tree rings (last few centuries), (3) the study of the ecophysiological, biogeochemical and demographic changes in our ecosystems in response to the changing climatic conditions (last few decades and years), (4) the experimental study of our ecosystems, under more or less controlled conditions, simulating the changes predicted for the next few decades by the climatic models and, lastly, (5) the modelling of past and future changes, in space and in time. Apart from using palaeoecological and historical tools to travel through time, the study of climate change and of its effects require to successively follow the spatial scale upwards, from the leaf to the ecosystem, the region and the whole planet, combining the modelling tools with those used for tele-detection. We must point out, however, that the influences of climate change are difficult to separate from those of the other components of global change, such as changes in biogeochemical cycles or changes in land uses.

2.1.7. Contents of the chapter and clarifications

Given the broad scope of aspects included in this chapter, a certain overlapping with other chapters is inevitable, especially with those dealing with forestry (Chap. 9), plant biodiversity (Chap. 5), animal biodiversity (Chap. 6), and edaphic resources (Chap. 8). In order to minimise this overlap, we have gone more deeply into the ecophysiological aspects of the vegetation and into processes operating at the levels of community and ecosystem. We will highlight the Mediterranean region, as it is the largest region of the Iberian Peninsula and because more information is available on its sensitivity to climatic change. Indeed, this region contains formations which have reached the limit of their possibilities, with hydric balances in which rainfall is equalled by evapotranspiration. The freshwater and coastal systems are dealt with in other chapters (Chaps. 3 and 11 respectively). By the term increased aridity, we refer jointly to the decrease in rainfall, which in turn is becoming more irregular, and to the temperature increase, which leads to an increased evapotranspiration.

2.2. SENSITIVITY TO THE PRESENT CLIMATE

2.2.1. History of climate change and of anthropogenetic influence in ecosystems

Our country, like the whole planet, is subjected to environmental change, a change that has been very spectacular in different phases of the history of the earth, but which is currently occurring at a particularly accelerated rhythm (IPCC 2001). European terrestrial ecosystems have undergone multiple and profound changes related to equally profound climatic changes accompanied in more recent times by alterations in the regime of disturbances (e.g. grazing, fire, charring and extraction of timber). It must be pointed out that the adaptational and competitive characteristics of the species and stochastic processes have been as important, if not more, as the conclusion of the glacial phases and the climatic changes of the Holocene with regard to the establishment of dominant species following each crisis (Carrión 2003).

The Iberian Peninsula and the Balearic Isles have been of great biogeographical value in the study of climatic changes during the last glacier-interglacial cycle. Following the so-called Riss-Würm interglaciation, between around 120,000 and 80,000 years before the present, the pollen registers suggest the expansion of steppe landscapes that responded to low rainfall and temperatures (Pérez-Obiol and Julià 1994). Nevertheless, during the last glacial crises, some mountain and coastal areas in the South of the Peninsula maintained a climate that was warmer and more humid which represented an important uniqueness in the peninsular environment and reflects a landscape that was eventually more wooded with the inclusion of mesophyll and thermophilic species (Carrión 2002, Carrión *et al.* 2003). The most noteworthy information on centennial and millennial pulses from the last glaciar-interglacial cycle comes from the period known as Lateglacial which began around 14-15,000 years ago. This period involved a global climatic improvement, concurrent with the deglaciation process, which favoured the development of tree and shrub formations in many regions of the Peninsula, although the nature of this colonisation is transgressive. Subsequently, between 11,000 and 10,400 years, a climatic anomaly occurred, which meant a step backwards by several centuries to the cold and arid conditions of the pleniglacial. We are referring to the recent Dryas (in reference to the alpine Rosaceae, *Dryas octopetala*). The end of the recent Dryas constitutes the start of the present interglacial (Holocene) which is characterised by a rapid increase in temperature and humidity reaching optimum level around 8,500-5,500 years before present. Between 5,000-4,500 years, climatic parameters acquire a Mediterranean character in the South, the East and in the Balearic Isles (Yll *et al.* 1997) and in many parts of Eastern Iberia, greater seasonality and a more xeric landscape are observed. In the West and North of the Peninsula, this climate change did not manifest itself in such an abrupt manner, but the bioindicators permit us to establish a reduction in rainfall. The last 3,000 years are characterised by phenomena of generalised deforestation, above all in the thermo-Mediterranean context, caused by the aforementioned synergy of climate and anthropic action.

Although most of the pollen sequences do not reach the adequate resolution to distinguish questions below multi-millennial change, some suggest that changes in vegetation may occur in very few centuries or even decades, as a consequence of abrupt climatic changes. On the Iberian Peninsula, only one Holocene pollen sequence revealed these dynamic plant responses to climate change, that of Cañada de la Cruz, at the upper forest limit of Sierra de Segura mountain range (Jaén) (Carrión *et al.* 2001). These changes have forced the relatively rapid altitudinal or latitudinal migration of different species. At even shorter temporal scales, the studies of herbarium material show that in the last two centuries, stomatic density has fallen by 21% and the discrimination of the ^{13}C by 5.2%, suggesting the influence of an adaptation process (increased efficiency of water use) as a response to variations in selective pressure determined by the warmer and more arid conditions of the present (Peñuelas and Matamala 1990, Peñuelas and Azcon-Bieto 1992).

It ought to be mentioned that in recent years, evidence has been found of a rapid biotic response (decades-centuries) to the abrupt climatic changes occurring at the heart of the glacial phases (the so-called Heinrich and Dansgaard-Oeschger events, which can be seen in the ice cores in the Antarctic and Greenland). These responses seem to include the continental vegetation of the Southern Peninsula, as has been seen in certain marine sequences in Alborán and on the Iberian Atlantic and North African coasts (D´Errico and Sánchez Goñi 2003). Very recently it has been proven that the sign of climate change also appears in the geochemistry of speleothemes (Genty *et al.* 2003). Given that the marine sequences provide a pollen rain of uncertain spatial control and that they have a complex taphonomy, we should wait for the appearance of continental records to confirm or reject the fact that the responses of vegetation to interglacial events have been equally brusque. The preliminary reports on European palaeovegetation during the Marine Oxygen isotopic stage 3 (*OIS 3 Project*) are not conclusive in this sense (Huntley *et al.* 2003).

Among the country's terrestrial ecosystems, forests and shrublands have spread over the last few decades as a result of the temperature rise, of the increased CO_2, and/or of the increase in fertilisers in the atmosphere (diffuse eutrophication), but above all as a result of two processes of anthropic origin: secondary succession based on pastures and abandoned crop fields, and the superposition of successive severe disturbances upon the terrestrial ecosystems (Mesa-Jimenez 2002, Costa *et al.* 1998). The different uses that humans have made of them have produced a mosaic of ecosystems with varying degrees of maturity, forming heterogeneous landscapes that favour the maintenance of diversity.

2.2.2. The "fingerprints" of climate change in the trees of the Iberian Peninsula

The growth rings in timber from trees reveal big inter-annual oscillations in response to the climatic changes of the last few centuries, although these oscillations differ among species. Species tolerant to drought, but which can make use of the phreatic water, such as the Holm oak (*Quercus ilex*), show less oscillation than the species that elude drought, and depend more directly on rainfall, like the Aleppo pine (*Pinus halepensis*) (Ferrio *et al.* 2003). Throughout the 20th century, trees, forests and ecosystems have been responding to effects of climate change like increases in CO_2, global warming and climatic variability. The response of the trees to these effects has been analysed in over 60 forests of conifers of different environmental characteristics throughout the whole eastern half of the Peninsula. Most of the dendrochronological variables (based on the thickness of the annual rings, their isotopic composition and changes in the anatomy and density of the wood) showed a growing variability during the second half of the 20th century, reflecting an increase in climatic variability and in the frequency of extreme events (Tardif *et al.* 2003, Camarero and Gutiérrez 2004). Climate change has restricted the possibilities for change of the trees, which show greater synchronisation in their growth, both among individual trees and among species. This means a reduction in the differences between sites due to local causes (slope, orientation, substrate, or influence of a determined type of climate), which have acquired secondary importance in the last few decades. These effects have been observed for different spatial and temporal scales. Among the changes detected are: a) an increase in intra-annual variability in growth in the thickness of Mediterranean tree species, in *Pinus halepensis*, related to the lengthening of the growth period; and b) an increase in the inter-annual and inter-decade variability in the series of ring thickness and of the isotopic composition in populations of sub-alpine trees at local and regional scale (Camarero and Gutiérrez 2004).

During the 20th century, two very contrasted periods have been described, based on the radial growth of Mountain pine *Pinus uncinata* in the central Pyrenees: (*i*) the first half of the last century showed a low frequency of wide and narrow growth rings, low average sensitivity and a low proportion of common variance among trees, whereas (*ii*) the second half presented the opposite characteristics (Tardif *et al*. 2003). The lower variability in growth between 1900 and 1950 has been associated with a "relaxation" of the altitudinal thermal gradient due to the greater regional warming observed during these decades and to a lower inter-annual climatic variability of the temperatures. Further up, at the upper limit of the forest, the recent increase in this climatic variability since 1950 has stopped the altitudinal limit of the tree from rising (Camarero and Gutiérrez 2004). In contrast, in the climatically warm and stable period from 1900-1950 a clear rise in the limit of the tree was observed. The increase in climatic variability since 1950 has slowed this rise, favouring an increase in density within the sub-alpine forest – alpine pastures ecotone.

2.2.3. Sensitivity to temperature and direct responses of organisms and systems

The activity of all living organisms is strongly influenced by temperature. Thus, we cannot expect anything other than alterations of this activity. And the first type of change provoked by warming is in the life cycles of plants and animals (Peñuelas and Filella 2001). These phenological changes have become the clearest symptom of the fact that climate change is now affecting life (Fig. 2.1). At individual level, the most direct physiological effect of the temperature increase is the rapid increase in the respiration rate. The respiration of the whole ecosystem, the main component of which is plant respiration, is the determinant process of carbon balance, at least in European forest ecosystems which have been studied with sufficient accuracy (Valentini *et al.* 2000). The high temperatures affect the photosynthesis of plants, but these are capable of becoming acclimatised and of growing even at extreme temperatures, provided that water is not a limiting factor. The high temperatures increase the deficit of vapour pressure, increasing the plants' transpiration. But the closing of the stomata, frequently exacerbated by the combination of high temperatures with drought and high levels of CO_2, can even make transpiration diminish (Kirschbaum 2004). The capacity of the plants to become acclimatised to different temperatures, particularly during their development, stops respiration from increasing as rapidly with temperature as could be expected, but in spite of the big impact of plant respiration on the productivity of ecosystems, there are still many physiological uncertainties (Atkin and Tjoelker 2003).

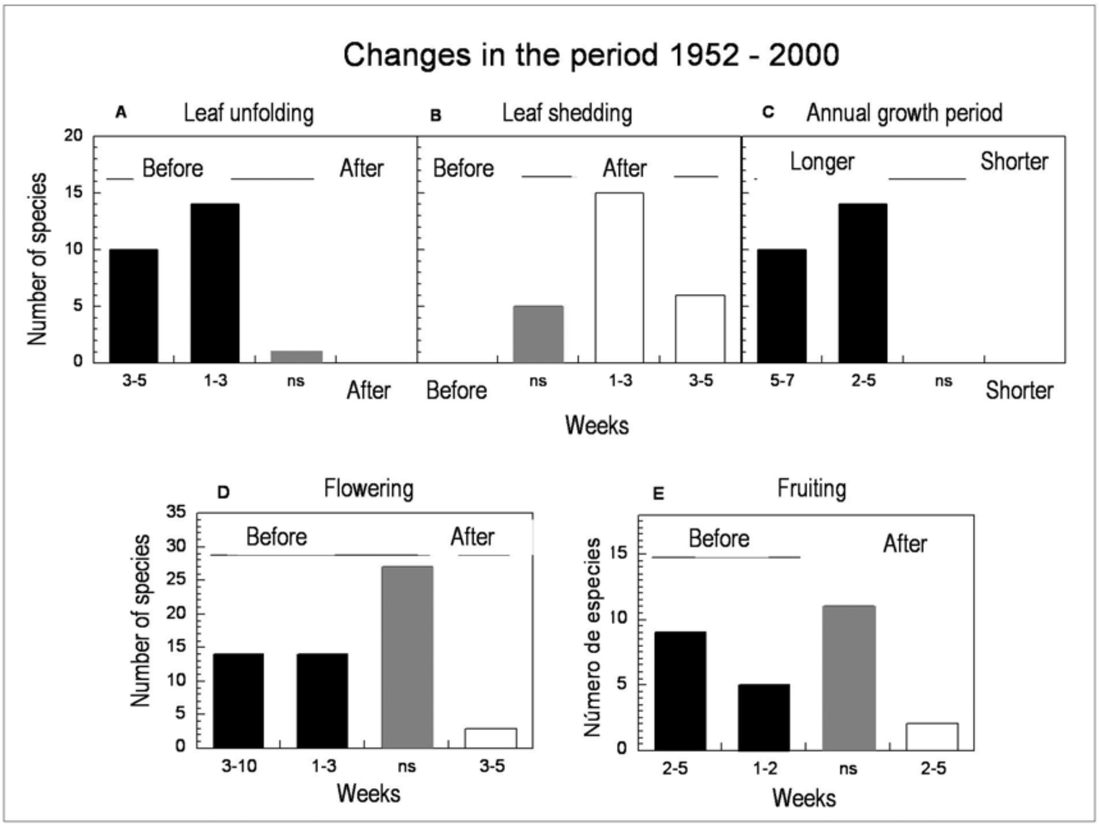

Fig. 2.1. *Frequency of plant species with life cycles that have been altered in the last five decades (from 1952 to 2000) in Cardedeu (Vallès Oriental, Barcelona). Before and After refer to the moment of the event, that is to say, if this is advanced or delayed respectively during the period studied: ns = not significant. (After Peñuelas et al. 2002).*

But it is not only organisms that are affected by warming, but also ecosystem processes. Given that biogeochemical processes depend on temperature, eutrophication, or enrichment in nutrients, is sensitive to warming, above all nitrates, a very worrying process at international level. Although eutrophication is generally associated with the occasional or diffuse contribution of nutrients (e.g. excess of cattle faeces, fertilisers), increased temperature and droughts have a great influence on the dynamics of nutrients, due to the fact that warming increases mineralisation, and that the drought impedes the use of nutrients by the plants and facilitates losses by the system with rain. Another similar biogeochemical alteration lies in the stimulation of the decomposition of organic matter by warming (see chapter on edaphic resources). The lack of water, conversely, retards this. It is therefore a situation in which two factors involved in climate change have different effects (even conflicting ones) on the cycle of the material and the functioning of our ecosystems (Emmet *et al.* 2004). In pastures in the Catalonian Pyrenees which are not limited in the hydric sense, it has been seen that warming increases productivity and accelerates the decomposition of organic matter (Sebastiá *et al*. 2004).

2.2.4. Phenological changes and desynchronisation between trophic levels in a warming world

Due to its situation and topography, Spain is one of the places in which the phenological changes are expected to be biggest. The biological cycle of many common plants, migrating birds and species of butterflies and other insects is changing significantly and climate change seems to be the main cause of this alteration (Fig. 2.1). In Catalonia, the leaves of the trees unfold, in general terms, 20 days earlier than fifty years ago. The leaves of the apple tree, the elm or the fig tree seem to sprout a month in advance and the almond tree and the poplar, fifteen days before, although some other trees, like the chestnut, seem impervious to changes in temperature due to being more dependent on other factors such as the photoperiod or water availability in the soil. Furthermore, plants are also flowering and fruiting an average of 10 days earlier than 30 years ago (Fig. 2.1). And the life cycles of animals have also been altered. For instance, the appearance of insects that go through the different larval states faster in response to warming, with an average advance of 11 days (Stefanescu *et al.* 2004). All this premature activity of plants and animals may endanger them by means of late frost episodes. But the frequency of these episodes has also changed, generally diminishing in an environment that is getting warmer and warmer. For example, in Cardedeu (Barcelona) there was frost around 60 times a year and now there are about 20 (Peñuelas *et al.* 2002). Similar responses in the advance of the phenophases of plants and animals (invertebrates, amphibians, birds....), by around 3-4 days in spring, have been recently described in many other parts of the world (Peñuelas and Filella 2001, Walther *et al.* 2002, Parmesan and Yohe 2003), so that this seems to be a generalised phenomenon, with the regional, local and specific variability typical of all biological phenomena. All these phenological changes are not simple indicators of climatic change. They are of critical ecological importance because they affect the competitive capacity of the different species, the conservation of these, and therefore, the structure and functioning of the ecosystems. As nature is not homogeneous, the responses to warming are different depending on the species and even on the individuals. Such heterogeneous responses to climate change may cause serious de-synchronisations in the interactions between species, for instance, between plants and their pollinators, as in the case studied by Santandreu and Lloret (1999), or between plants and herbivores, thus altering the structure of communities. A paradigmatic example of the desincronizaciones between trophic levels can be seen in what occurs with migrating birds. Given the advance in the flowering and fruiting of plants and in the appearance of insects, and therefore, the advance in the availability of food for birds, we can expect an earlier arrival of migrating birds. But this is not so, because the arrival of certain very common and popular birds like the nightingale, the swallow, the cuckoo or the quail is being retarded in certain areas by an average of two weeks in relation to thirty years ago (Peñuelas *et al.* 2002). This delay is surely determined by climate change in the place they emigrate from, the sub-Saharan regions, or in the regions they pass through on their migratory routes. However, studies already underway reveal a complex spatial pattern, with parts of the country where the birds arrive earlier (see chapter on animal biodiversity).

If we observe the phenological changes at global scale, we can see very important alterations such as, for example, the increase by 20% in the biological activity on our planet in the last 30 years, very much due to this phenological retardation of the productive period (Peñuelas and Filella 2001). We can appreciate this increase both in the pictures from the satellites for observation of the Earth, and in the data on atmospheric concentration of CO_2. The normalised data on the vegetation index (NDVI) corroborate the data from the observation of the Earth and show how in the last 20 years the growth season of plants has been lengthened by 18 days in Eurasia, which has led to an increase in green biomass, at least at latitudes 40º (Myneni *et al.* 1997). The increase in plant productivity in the last few decades which had been attributed to the fertilising effect of the CO_2 and to nitrogen depositions, may also be partly due to this temperature rise and to this lengthening of the growth season (vegetative activity). All of this is corroborated by the data on atmospheric concentration of CO_2, which show us an increase in the range of seasonal oscillation of CO_2 in the last few decades due to the greater springtime drop in the concentration of CO_2 (Keeling *et al.* 1996).

2.2.5. Another effect of warming: more emission of volatile organic compounds

The temperature increase has diverse direct effects on the activity of living organisms. One environmentally important one is the exponential increase in the biogenic emission of volatile organic compounds (VOC). These emissions affect atmospheric chemistry, not only in relation to the carbon cycle (emissions of around 1500 Tm C year^{-1}) and to the formation of aerosols, but also to the role they play in the oxidative balance of the levels of OH, NOx and O_3 (Peñuelas and Llusià 2001). Emissions of VOC are controlled by the factors that alter the tissue concentration of these compounds, vapour pressure and resistance to diffusion into the atmosphere. Temperature exponentially increases the emission of VOC on activating its enzymatic synthesis and its vapour pressure and on decreasing resistance to emission. Drought, however, reduces the emissions due to the lack of carbohydrates and ATP, and to the decrease in the permeability of the cuticle to the exchange of gasses. At the present time, it is difficult to estimate the final result of this antagonism between warming and drought. Other factors linked to global change, like the increase in tropospheric ozone also affect the emissions of VOC; these is a phenomenon of positive feedback from pollution by ozone, which requires greater attention in order to correctly understand it (Llusia *et al.* 2002). One of the most important apparent functions of some of these VOC, like isoprene and the terpenes, is to act as thermoprotectors. *Quercus ilex* seems to use these compounds as stabilisers of the cell membranes and also as deactivators of the of the oxidised radicals to protect itself from the high summer temperatures (Peñuelas and Llusia 2002). Furthermore, these emissions of VOCs could provide a negative feedback for the warming of the atmosphere itself, on acting as aerosols that decrease irradiance, although they could also provide positive feedback for warming by means of their direct greenhouse effect, by absorbing infrared radiation, and of the indirect one, that is, lengthening the life of methane and other greenhouse gasses (Peñuelas and Llusia 2003).

2.2.6. Sensitivity and response to drought

Hydric availability is a critical factor for evaluating the effects of climate change on most terrestrial ecosystems. Warming and drought should be considered simultaneously. Indeed, both the lengthening of the life of deciduous trees and the acceleration of the renovation of the leaves of evergreens, phenomena associated with temperature increase (Gracia *et al.* 2001, Sabaté *et al.* 2002), will lead to an increase in the water transpired which is added to the greater potential evaporation resulting from the temperature rise. In those places in which the forest avails of sufficient water to compensate for this greater hydric demand, forest production can be expected to increase. However, in the places subjected to hydric deficit, which represent most of the terrestrial ecosystems in Spain, changes can be expected which will range from a reduction in the density of the trees to alterations in the distribution of species (Sabaté *et al.* 2002).

Droughts can be moderate or extreme, chronic or acute, recurrent or sporadic, and the responses of one same species can vary depending on these characteristics and on the moment and speed with which the drought sets in. Predictions of climate change indicate an increase in the duration and intensity of droughts during the 21st century, associated with a more irregular rainfall regime and with more extreme and generally higher temperatures (IPCC 2001). The spatial heterogeneity of these variables, especially of those related to the rainfall regime, is high, and it is therefore currently difficult to make predictions for specific areas. This climate change will undoubtedly give rise to local extinctions and changes in species dominance in many terrestrial ecosystems. Drought limits plant growth and survival, acting as a selective stress filter of plants, according to their tolerance to hydric stress. It also negatively affects reproduction and alters the production rhythm of leaves, stems, flowers and fruits (phenology). In spite of the apparent recovery of tree cover following unusually intense droughts, there are indications that generalised droughts leave consequences that persist for several years (Peñuelas *et al.* 2000). The increasingly frequent repetition of drought episodes could accelerate these changes at community level (Valladares *et al.* 2004c).

In a comparative study of the hydraulic architecture of nine woody species, it was seen that whereas *Ilex aquifolium, Phillyrea latifolia* and *Juniperus oxycedrus* were resistant to the cavitation of the xylem caused by drought, *Quercus ilex, Arbutus unedo* and *Acer monspessulanum* were much more vulnerable (Martinez-Vilalta *et al.* 2002b). It was also observed that this different vulnerability to cavitation was correlated to the hydric potentials that each species showed in the field, confirming the existence of different hydric strategies that make the species growing together spend the summer drought with different stress levels and with different safety margins with regard to embolisms. Analogous differences have been observed in *Quercus coccifera* and *Pistacia lentiscus* (Vilagrosa *et al.* 2003).

We can learn about the effects of heat and drought from examples of hot, dry periods such as those of the summer of 1994. This summer severely damaged many forests and shrublands on the Iberian Peninsula (80% of the 190 peninsular sites studied presented damaged species, Peñuelas *et al.* 2001). The Holm oaks, for example, dried up in many sites (Lloret and Siscart 1995). In parts of the Iberian System mountain range in Aragón, intense defoliation was observed, along with drastic changes in anatomy and growth, but the Holm oaks recovered after the drought (Corcuera *et al.* 2004). Isotopic studies with ^{13}C and ^{15}N showed that in the following years these Holm oak forests continued to be affected, so that they presented less use of the water that was available to them, and the loss of soil nutrients was favoured (Peñuelas *et al.* 2000), a serious secondary consequence, if we take into account that these ecosystems are usually limited by nutrients (Rodá *et al.* 1999). The different severity of the effects on the different forests in the country was determined, among other factors, by 1) the orientation of the slopes (greater damage on the sun-facing slopes) (Peñuelas *et al.* 2000), 2) soil lithology (less damage in the deeper soils that were more penetrable by the roots, for example, soils on schists) (Lloret and Siscart 1995), 3) the dominant species (Peñuelas *et al.* 1998), and 4) forest management (thinned forests less affected than the dense ones) (Gracia *et al.* 1999). The degree of damage varied depending on the functional type and on the evolutionary history of the different species (Peñuelas *et al.* 2001). The genera, *Lavandula, Erica, Genista, Cistus* and *Rosmarinus*, that have diversified under the Mediterranean climatic conditions (i.e. after the 3.2 million years of the Pliocene) were initially more affected by drought than genera that had evolved previously (e.g. *Pistacia, Olea, Juniperus, Pinus* and *Quercus*), but recovered much better after several years of greater water availability. An non-native genus *Eucalyptus* was seriously damaged by the drought and did not recover in successive years. The post-Pliocene Mediterranean species, therefore seem to be more resistant to an environment that is difficult to predict, with great seasonal and inter-annual variability and subject to frequent droughts (Fig.

2.5). An understanding of these responses is important in order to predict the future composition of the communities in a scenario of climatic change.

2.2.7. The importance of disturbances and their interaction with climate

Many terrestrial ecosystems and in particular the Mediterranean ones, have been and are exposed to disturbances that may be episodic, such as intense drought and fires, or chronic, like overexploitation and herbivory. Fire, and subsequently, grazing, had a very significant influence upon the evolution of the vegetation during the second half of the Holocene. The increase in aridity was, in many cases, little more than a background influence. Given the frequency and intensity of the disturbances suffered by Mediterranean ecosystems, the differential sensitivity of the species to these is a very important mechanism in the composition and spatial and temporal dynamics of plant and animal communities. But climate can cause significant variations in the effect of the disturbances on the ecosystems. The effect of herbivory, for example, can cause drastic changes under more xeric conditions (Milchunas *et al.* 1988). In the short term, overgrazing generates the consumption of much of the primary production and accelerates soil erosion. In the long term, it may lead to an increase in the abundance of unpalatable species, apart from a generalised collapse in the regeneration of woody species. Damage by herbivory of woody plants depends on the amount of annual rainfall, and the impact is greater in the dry years (Zamora *et al.* 2004).

The hotter and more arid conditions, along with the increase in biomass and in the inflammability of this associated with the increase in CO_2, the changes in land use, such as the abandonment of crop fields followed by a process of forestation and accumulation of fuel, and the activities of a growing number of visitors to our forests, increase the frequency and intensity of forest fires. Mediterranean forests and shrublands, characterised by severe summer drought, are ecosystems prone to fires. Fires, which increased throughout the 20th century, now constitute one of the most serious disturbances in Mediterranean region (Moreno *et al*. 1998, Piñol *et al.* 1998). This increase is partly due to the abandonment of the countryside and to previous reforestation programmes using pine species that result in very inflammable forest formations. The vegetation-fire relationship, however, is a complex one (Moreno y Vallejo 1999, Moreno *et al* in press *a,* Ojeda 2001; see chapter 12). Fire causes intense disturbance of vegetation and landscape: at historic or evolutionary scale, it has acted as a selective filter of plant and animal species; at ecological scale, it creates open spaces, changes the structure of the habitat and the supply of food for the fauna, and determines spatial mosaics of regeneration which, depending on the spatial scale and recurrence of the fires, can generate greater diversity. The structural composition of the species, and therefore of the community as a whole, is modified, as has been seen in the response of Mediterranean plant species in the different conditions of fire recurrence simulated in the Garraf Nature Park in Catalonia (Lloret *et al.* 2003). Furthermore, the increased intensity and frequency of fires, the synergic effect of other severe disturbances, such as excessive herbivory, causes nutrient losses in the ecosystem, negatively affects species with strict forest requirements and those that have no suitable persistence or dispersion mechanisms, and can finally lead to a simplification of the composition and structure of the communities (Ojeda 2001).

2.2.8. Direct effects of increased atmospheric CO_2

All the aforementioned factors, water availability, temperature, fires, VOC and nutrients, interact with the main factor generating climatic change, the increase in atmospheric CO_2. Given that CO_2 is the substrate of photosynthesis, thousands of studies have been carried on the direct effects of the increase in atmospheric CO_2, mostly at short temporal scales, under controlled conditions and with young plants (Körner 2000). In general, an increase in photosynthesis rates has been observed, along with less tissue concentrations of N and a reduction of transpiration which leads to the more efficient use of water (Kirschbaum 2004). The final effect of the increase in CO_2 however, depends on the interaction with other environmental factors: temperature, radiation, drought, availability of nutrients or the presence of atmospheric pollutants. Responses to CO_2 are different depending on species, and even on genotypes (Castells *et al.* 2002), which could lead to changes at community level, as the concentration of this gas increases. It is still very unclear what may happen in the long term and even less under the real complex conditions of the ecosystems (Körner 1995, Körner 2000). For instance, the responses observed could be buffered in time; indeed, in some plants, acclimatisation of the photosynthesis and the disappearance of the reductions in concentrations of N have been observed after six years of growth at high CO_2 (Peñuelas *et al.* 1997). The increase in CO_2 could increase the synthesis of secondary metabolites in plants, which could provide protection against pests and pathogens, but on increasing the C/N relationship, consumption by herbivores may be stimulated and the quality of the organic matter in the soil could worsen (Sebastiá *et al.* 2003). In short, the tendencies to be expected in the photosynthesis rates with an increase in CO_2 have been confirmed in recent reviews, but not the tendencies related to primary production, which vary according to species (Poorter and Navas 2003) and interacts in a complex manner with other resources such as water and nitrogen (Nowak *et al.* 2004). In the scaling of ecosystems there is an increasing uncertainty caused by the diverse climatic factors operating together with the increase in CO_2 (Norby and Luo 2004).

2.2.9. Capacity of species to evolve and to adjust to phenotypical plasticity

From the evolutionary point of view, species tend to be quite conservative and to respond to disturbances by migrating rather than through adaptation. But migration in the currently fragmented landscape is quite unlikely. The slowness of certain ecological processes, like the natural regeneration of some species of the genus *Quercus*, compromises the long-term viability of the ecosystem, as one of the characteristics of climate change is the acceleration of change rates. Microevolutionary processes can occur on short time scales in dynamic systems such as temporary lakes, thus compensating for the negative effects of a very rapid environmental change rate. But these processes are not operative for long-lived, slow-growing species such as Holm oaks and other oaks, essential in many of our terrestrial ecosystems (Rice and Emery 2003). The capacity for ecophysical adaptation to local environmental conditions is noteworthy in most plant species, but the problem is the rapid rate of environmental change, above all for woody species, in which evolutionary adjustments require 200-1200 years in order to be effective, as has been estimated in *Pinus contorta* (Rehfeldt *et al.* 2001). If the plants cannot follow climate change by evolution, they can attenuate its adverse effects by means of short-term responses (acclimatisation, phenotypical plasticity). But plasticity has not generally been maximised during evolution in adverse systems (e.g. arid areas or ones poor in nutrients or subjected to climatic extremes), but rather the species in these areas tend to make conservative use of the resources involved in moderate plasticity (Valladares *et al.* 2002). It could therefore be thought that the capacity for physiological and morphological adjustment to new climatic conditions is initially limited for certain species or populations in Mediterranean areas and perhaps also for high-mountain species on oligotrophic soils.

2.2.10. Sensitivity of ecosystems to climate change within a framework of interactions

Ecosystems are, by definition, characterised by the existence of interactions both between biotic and abiotic factors and among the living organisms. If the information on sensitivity to climate change is deficient for many species, it is even more so if we want to take these interactions into consideration. These interactions are crucial, however, for interpreting the sensitivity of ecosystems. For example, if one determined species requires the intervention of another species to complete its life cycle (e.g. a pollinator for a plant), knowledge of the sensitivity of the former to climate change is of little use to us if we know nothing of the sensitivity of the latter.

Changes in the phenology and distribution of many species will contribute to separating in space and/or in time species that until now have coincided in the same habitats, but also to make contact between species that had had no interaction until now. That is to say, climate change is favouring both the rupture of interactions and the establishment of new ones. An example of new interactions is being observed in Mediterranean mountains in the behaviour of the pine caterpillar (*Thaumetopoea pityocampa*), a defoliator of diverse pine species (Hódar and Zamora 2004). The interactions are crucial for interpreting the sensitivity of ecosystems to climatic change, as in the case of the Scots pine, for example, the autochthonous populations of the endemic variety Sierra Nevada seem to be able to resist well recent climatic changes, but the rise in winter temperatures is causing the pine caterpillar to rise altitudinally, infesting the native populations of Scots pine situated further up the mountain (Hódar *et al.* 2003). Studies of the interactions among plants reveal a general pattern of change of sign from negative (competition) in favourable conditions to positive (facilitation or mutualism) in adverse conditions (Pugnaire and Luque 2001). In experimental reforestation carried out along a broad environmental gradient in Sierra Nevada, it has been found that the magnitude of the facilitation of pioneer shrubs towards seedlings of woody species increases at low altitude and in exposure to sun-facing slopes, where there is greater abiotic stress (Gómez-Aparicio *et al.* 2004). To the contrary, at greater altitudes and northern exposure, with lower temperatures during the summer and above all more rainfall, the facilitation of the shrubland is much less evident.

Recent studies show that the type of interaction can also be negative when the stress level is very high and not only when the conditions are favourable (Maestre and Cortina 2004) (Fig. 2.2). There is current evidence of temporal changes in the magnitude and sense of the interactions, for instance between *Pinus halepensis* and resprouting shrub species, which are probably related to the inter-annual variation in climatic conditions (Maestre *et al.* 2003). In any case, it is clear that climate change will affect the intensity and sign of the interaction between species and an additional source of evidence in this respect lies in the phenological studies of temporal phase differences between trophic levels, with profound but unpredictable consequences for the structure and functioning of ecosystems (Fig. 2.3).

Not only species interact, but also the factors influencing the processes. The two main climatic changes, temperature increase and reduced rainfall, interact, giving rise to synergies, when they both stop or accelerate a process, but more frequently to antagonisms, when the effect of one has a sign opposite to that of the other (e.g. in plant productivity or microbial activity of the soil, as, while temperature increases activity, drought reduces it). Other factors that interact and merit particular attention are, for instance, radiation and drought. With the abandonment of the countryside and the general darkening of the atmosphere by the increase in aerosols and cloudiness, there is increasingly less light available for the regeneration and growth of plants (Valladares *et al.* 2004a). The combination of this darkening with increased drought gives rise to a growing frequency of dry shades which imposes a double limitation on the regeneration of many plant species and about which we still know very little (Valladares and Pearcy 2002, Valladares 2003, Valladares *et al.* 2004b).

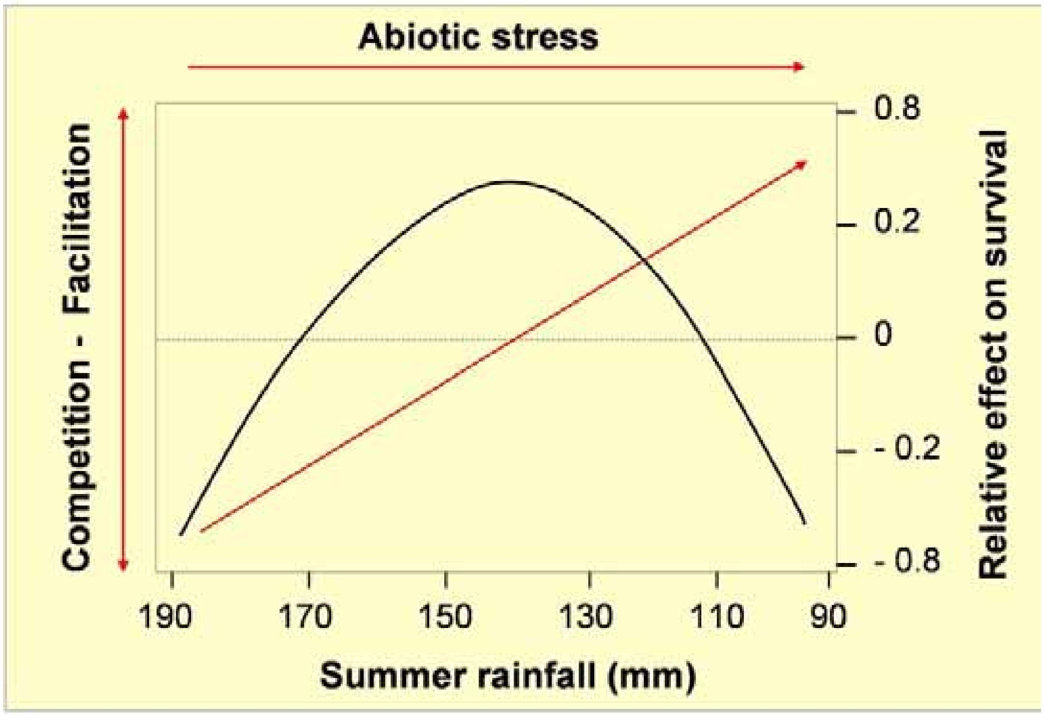

Fig. 2.2. *Interaction among species according to abiotic stress. Whereas different studies show that, as stress increases, the interaction among the different plant species of a community changes from competition to facilitation (red arrow), in conditions of intense stress there may be competition in conditions of little stress. The black line indicates the relative effect of* Stipa tenacissima *on the survival of seedlings of* Pistacia lentiscus *according to the amount of rainfall in spring and summer in the semiarid region of Alicante (After Maestre and Cortina 2004). Climate change therefore has effects which are not only quantitative but also qualitative in the interactions between organisms (sign of interaction).*

2.2.11. Sensitivity of terrestrial ecosystems of islands

The terrestrial ecosystems of islands are generally subjected to a higher risk of extinction and functional alterations than their continental homologues, and the smaller the island the greater this is. Spanish island ecosystems (mainly the Balearic and Canary Isles) are rich in endemic species, many of which are sensitive to brusque climatic changes. Some of these species, like *Rhamnus ludovici-salvatoris* on the Balearic Isles, present little tolerance to drought and a poor photosynthetic performance if compared with the non-endemic species with which they coexist, such as *R. alaternus, Quercus ilex, Q. humilis, Pistacia lentiscus* and *P. terebinthus*, which has been interpreted as a consequence of their relictic and recessive nature (Gulías *et al.* 2002).

The plant species of the cloud forests of the Canaries, an ecosystem that currently occupies small and fragmented areas, are relics from less arid climates, and their sensitivity to climate change is therefore initially high. Indeed, some species of the cloud forest such as *Persea indica* can be used as indicators of climate change (Larcher *et al.* 1991). Several of the main species of these formations have very little capacity to regulate water loss through transpiration, and are therefore very sensitive to a fall in hydric availability (Zohlen *et al.* 1995, Cermak *et al.* 2002). Intense land use changes, the pressure applied to the ecosystems by the development of tourism and the reiterated introduction of exotic species, many of which become invaders, are serious threats which make the terrestrial ecosystems of islands very sensitive to climatic change. Other island ecosystems which share, to a certain extent, the aforementioned features and sensitivities are systems that are isolated or fragmented in general and particularly those called edaphic islands. Among the latter, gypsum ecosystems, those of serpentine soils and brine basins should be mentioned. These systems are very valuable due to their richness in endemisms and constitute nature biodiversity reserves, which are under threat, not only due to the low level of protection, and the total lack of awareness of their importance, but also to climate change itself: these ecosystems are to a certain extent immobilised due to their edaphic dependence and they contain numerous species with inefficient dispersion (Escudero *et al.* 2000).

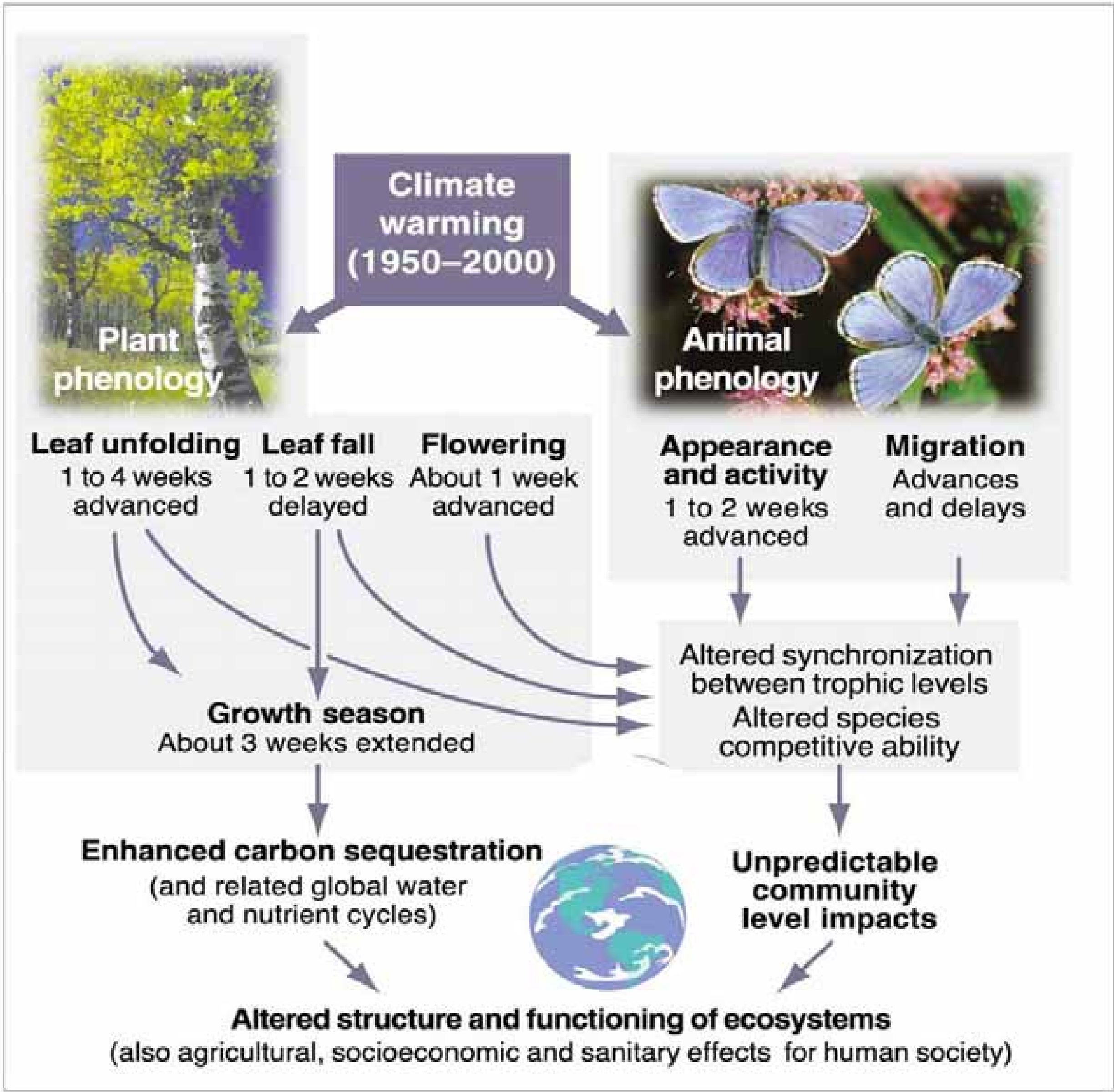

Fig. 2.3. *Ecological effects of the phenological changes caused by climate change (Taken from Peñuelas and Filella 2001)*

2.3. FORESEEABLE IMPACTS OF CLIMATIC CHANGE

2.3.1. Altitudinal and latitudinal migration

Europe's vegetation has migrated latitudinally and altitudinally in the different geologic periods as a response to the climatic changes registered. The main European woody species migrated latitudinally during the glaciations at rates of between 50 and 500 metres per year, and exceptionally, over one kilometre a year with the genera *Acer, Alnus, Carpinus* and *Ulmus* (Huntley and Webb III 1988). The upper limit of the forest, limited by temperature, advanced in the most favourable periods of the Holocene by between one and three centimetres a year and in the Central Pyrenees, advances have been recorded of between 20 and 80 centimetres a year during the last century (Camarero 1999). The predicted climate change would allow for the spread of thermophilic species, but the drop in rainfall would halt this advance, would harm those species that were not tolerant to drought and would negatively affect the lower limit of the forest (limited by hydric availability). Woody vegetation might spread towards the higher mountain areas and the communities already existing in these areas would become rarer or extinct. In many cases, the only possible migration is towards northern latitudes. But the migration rates would not be efficient in the current scenario of global change because, on one hand, the climate changes too fast, and on the other, the territory is very fragmented, which significantly restricts the real possibility of latitudinal or altitudinal migrations of the vegetation. It should also be pointed out that the Iberian Peninsula is the southern limit for the distribution of many species (e.g. *Pinus sylvestris*, *P. uncinata*) whose southern relictic populations are frequently isolated in mountain massifs.

In the mountains, species can respond to climate change by migrating vertically over short distances (for example, 500 metres is sufficient to counteract an increase 3°C). In Spain, and in general throughout the world, palaeoecological studies have shown numerous displacements from the distribution zones of certain species and plant formations in response to past climatic changes. But there still is not much evidence of responses to the present warming. Recently, the distribution of the vegetation in Montseny was compared with that of 1945 and the progressive substitution of temperate ecosystems (e.g. beech forests) by Mediterranean ones (e.g. Holm oak forests) was appreciated (Peñuelas and Boada 2003) (Fig. 2.4). Furthermore, beech forests have increased at maximum altitudes (1600-1700 m). Heathlands of *Calluna vulgaris* are also being replaced by Holm oak forests at medium altitudes, so that the Holm oak is now found at the unexpected height of 1400 m (Peñuelas and Boada 2003). Something similar has been observed in the Pañalara Massif, in the Guadarrama mountains, where the shrubs (*Juniperus* and *Cytisus*) are becoming increasingly abundant at altitudes at which pastures previously dominated (Sanz-Elorza *et al.* 2003) (Fig. 2.4). It must be remembered that in relation to the mountains, migration towards greater altitudes is accompanied by a reduction in the total area of each habitat, and the species with greater requirements related to area may become extinct. However, these observations of altitudinal migrations of key plant species in terrestrial ecosystems ought to be analysed with care, as the effects are not only attributable to climatic change. The decrease in cattle, with the consequent decrease in pressure by herbivores, and other changes in land uses, are to a certain extent involved in these migrations.

The analyses of the relationships between tree growth, the isotopic composition of the rings and climate indicate that the increase observed in the variability of this relationship is associated with an increase in the variability of meteorological oscillations at intra- and inter-annual, and inter-decade scale (Camarero and Gutiérrez 2004). The synchronic response of the trees to a lower number of environmental variables is seen as a reduction of the number of limiting climatic variables, which are in turn more stressful. The effect can also be seen in a lower level of successful establishment above the tree limit in places that have not been directly disturbed by anthropic activity. Thus, the negative relationship between the advance rate of the tree limit and the variability of temperatures in some months (e.g. march) suggests that the rise of the trees to greater elevations due to temperature increase (in specific parts of the Pyrenees for which no information exists) is limited.

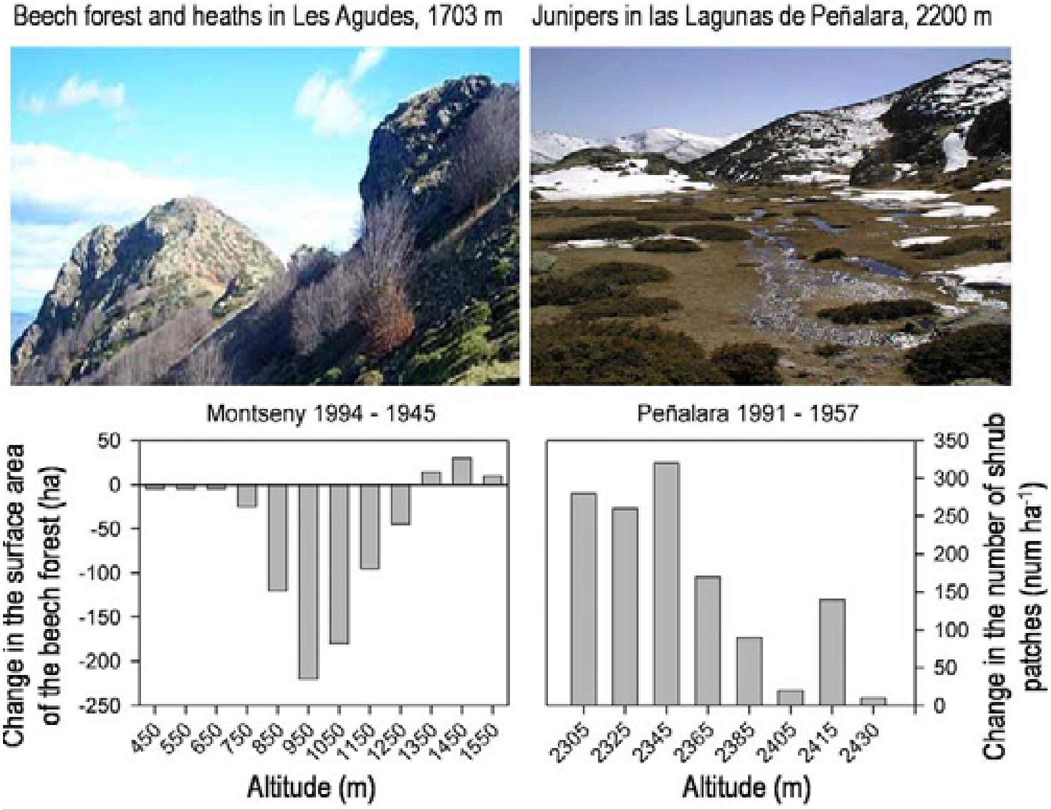

Fig. 2.4. *Altitudinal migration of plant formations in two mountains (Montseny Massif, Barcelona, and Peñalara, Sierra de Guadarrama mountains, Madrid) during the second half of the 20th century. In Montseny, the changes are shown in the area of the beech forests for a period of 49 years of progressive warming, along with changes in land uses (taken from (Peñuelas and Boada 2003), whereas in Peñalara the increase is shown in the number of patches of shrubs per hectare after 34 years (After Sanz-Elorza et al. 2003).*

2.3.2. Spread of pests and invasive species

Climate change will alter the interactions among species, bringing into contact many species that had hardly interacted previously. Some of these new interactions will involve parasitism, and the climate change will have a double impact (*per se* and through parasitism) in the host species. In the predicted scenarios of climatic change, certain thermophilic pests like the pine caterpillar could spread and in the case of the mountains reach species or populations that had never been affected by them. For instance, the impact of climate change in the autochthonous populations of Scots pine in certain Mediterranean mountains would be mediated by the pine caterpillar, typical of lower altitudes, and the interaction would therefore be more frequent, and not so much because of the direct effects of climate change itself on this species of pine (Hódar *et al.* 2003).

Invasive species are exotic species introduced voluntarily or involuntarily by man, and are capable of maintaining their populations in an independent manner, spreading and altering diverse key ecosystem processes (productivity, biogeochemical processes, etc.) (Mooney and Hobbs 2000). The invasive plant species have a great potential impact on the regeneration and natural dynamics of many terrestrial ecosystems, but there is little specific information on the impact that climate change could have on biological invasions (Valladares *et al.* 2004a). Evidence indicates, however, an increase in these invasions (Dukes and Mooney 1999).

Climatic alterations favour those invasive species that show a more plastic behaviour than their non-invasive homologues. It has been seen that certain invasive species or populations present greater phenotypical plasticity than the native species with which they coexist or than the non-invasive populations of these same species. This has been observed in comparisons of relictic populations of *Rhododendron ponticum* in southern Spain and invasive populations in Central Europe (Niinemets *et al.* 2003).

In certain populations, the climate change *per se,* and not the variability of this, would favour the invasive species. The spread of invasive plants can be predicted in clearings and underbrush, particularly under conditions of high CO_2 levels and/or high nitrogen levels. Many invasive plants are efficient colonisers of clearings and areas exposed to sunshine due to their high photosynthetic efficiency in direct sunlight, and they are capable of actively displacing the autochthonous species under these conditions (Pattison *et al.* 1998), whereas others efficiently invade the underbrush partly because they benefit proportionally more from an increase in CO_2 (Hattenschwiler and Korner 2003) or in soil nitrogen (Siemann and Rogers 2003) in shady conditions than the native species. The direct effects of climate change on invasions through ecosystem functioning could selectively favour the invaders over the native species, although there is very little available information. Tolerance to drought of certain invasive plants may also give them competitive advantages in dry shady conditions (Valladares *et al.* 2004a).

2.3.3. Changes in dominant species and reduction of productivity by drought

If the altitudinal and latitudinal movement of vegetation is unlikely, then drought and climatic extremes will cause change in communities and could lead to the local extinction of the worse adapted species. Changes in the dominant species of a community involve changes in its productivity, as has been seen in the productivity of herbaceous plants growing under different shrubs in semi-arid parts of the Iberian Peninsula (Pugnaire *et al.* 2004). These changes could therefore significantly affect carbon storage by plants. The progressive water crisis can already be seen in some Holm oak forests, and in pine forests and other Mediterranean forests at their hydric limit, with evapotranspiration rates equal to those of rainfall (Peñuelas 2001). In these forests, the worsening conditions of aridity during the summer could be the main reason or at least a factor of the mass decay of the trees. There are now clear indications that the increase in aridity and in temperature will not only negatively affect the net primary production of existing plant species, but will also lead to their substitution by other ones, more resistant to the new climatic conditions (Peñuelas *et al.* 2001, Martinez-Vilalta *et al.* 2002a). For instance, the increase in climatic aridity could compromise the survival of several populations of *P. sylvestris* in the Mediterranean basin (Martínez-Vilalta and Piñol 2002) and species like *Quercus coccifera* and *Q. ilex* could be gradually replaced by species that are more resistant to drought, such as *Pistacia lentiscus* and *Phyllirea latifolia* (Filella *et al.* 1998, Ogaya and Peñuelas 2003, Vilagrosa *et al.* 2003). Based on the hydric strategies of the main functional groups of Mediterranean woody plants, it has been suggested that the first local extinctions would threaten the relictic lauroid sclerophylls of the Tertiary (e.g. *Myrtus, Arbutus, Viburnum*), followed by arboreal sclerophyll plants (e.g. species of *Quercus*), whereas those that would be less affected or even favoured would be the chamaephytes (e.g. species of thyme *Thymus* spp.), the xerophytic malacophyllous plants (e.g. rock rose *Cistus* spp.) and in general the summertime deciduous shrubs (Fig. 2.5). In the zones of the Peninsula that are now at their climatic limit for plant formations like thyme and sage fields, climate change could involve the permanent disappearance of plant cover and desertification, like what can now be seen in semi-arid rosemary fields in Murcia, where no re-colonisation ahs been registered ten years after cutting down the vegetation (Castillo *et al.* 1997). In the short term changes in the relative dominance of the woody species of the forest are already being registered, which confirm the predictions.

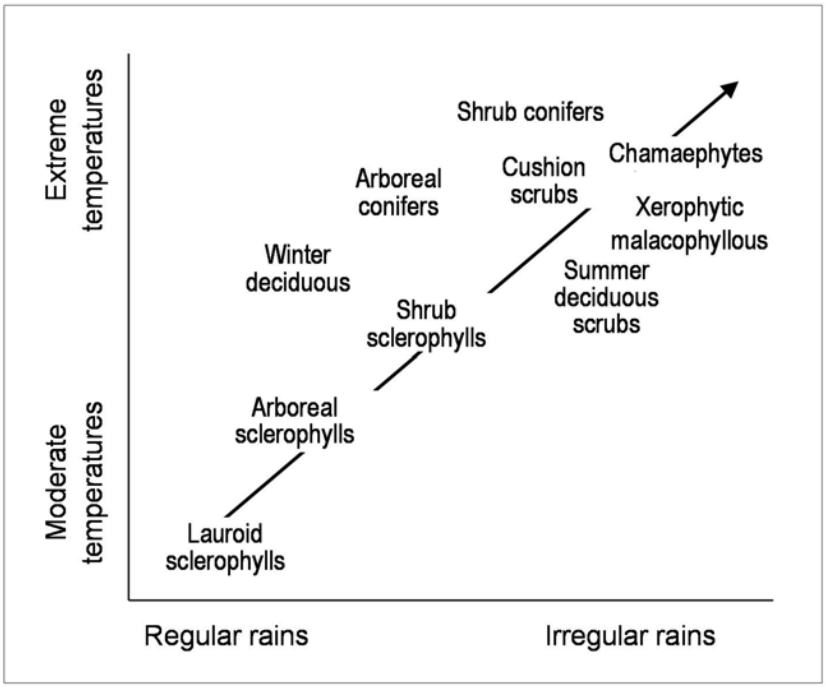

Fig. 2.5. *Distribution of the main functional groups of Mediterranean woody plants according to climatic conditions and impact related to climate change on their populations (arrow). The ordination of these groups according to the regularity of rainfall (correlated to aridity) and thermal extremes (continentality, heat waves) indicates that the lauroid sclerophyll plants (relics from the Tertiary) would be the first to be affected by climatic change, and would disappear, at least locally. However, the chamaephytes like thyme and malacophyllous shrubs like rock rose (which appeared following the establishment of the Mediterranean climate in the Pliocene) would be the least affected. In situations of cold winters, the sclerophyllous plants would be subjected to a proportionally greater impact than conifers and deciduous trees. (Reproduced from Valladares et al. 2004c).*

The experiments on drought and warming carried out in El Garraf (Barcelona) indicate that drought reduces the number of seedlings and their respective short-term species richness. This decrease also occurs, but in much lower proportions, in the treatment of warming in these same experiments. This effect occurs mainly in germination, and once the seedling has become established, its survival is affected little by the treatments. In general terms, the species that currently produce less seedlings are those that have more probabilities of disappearing in a drier climatic scenario (Fig. 2.6). When conditions are more severe, however, there are indications that the response of the species might be independent from the current abundance of their seedlings, that is, idiosyncratic (Lloret *et al.* 2004).

In an experiment consisting of the partial exclusion of rainwater and surface runoff, (15% decrease in soil humidity), different responses were observed among the dominant species, within the general tendency of growth reduction in drought in a forest dominated by Q*uercus ilex, Phillyrea latifolia* and *Arbutus unedo*. The drop in edaphic humidity retarded the cycles of water, of C, of N and of P, and affected the ecophysiology and demography of the species. Certain species are quite sensitive, like *Arbutus unedo* and *Quercus ilex*, whereas others like *Phillyrea latifolia* did not undergo any appreciable decrease in diametric growth (Ogaya and Peñuelas 2003, Ogaya *et al.* 2003). The death rate of the individuals showed a similar pattern, given that *Arbutus unedo* and *Quercus ilex* showed a higher death rate than *Phillyrea latifolia*. Under these drought conditions, the accumulation of total aerial biomass diminished by 42%, showing that under more arid conditions than the present ones, the growth rate of Mediterranean forests may be reduced to quite a great extent. Furthermore, considering that not all the plant species are equally affected, in the long run there could be a change in the specific composition of the forest, the drought-resistant species being more favoured. In this experiment the appearance and survival of new seedlings of *Quercus ilex* and *Phillyrea latifolia* were also studied. These species present different recruitment strategies in the forest studied: shoot and seed germination seedlings, respectively. The results indicate that the appearance of new seedlings of *Phillyrea latifolia* is more affected by the drought than the growth of new shoots of Holm oak. However these differences disappear with the development of the new plants, so that the survival of seedlings and shoots is similar not many years after. These results indicate that the effects of drought are greater in the initial development phases. Even so, the differences between species vary with the development phase: adult Holm oaks seem to be less resistant to drought than those of *Phillyrea latifolia*, but the models of recruitment are the opposite. Things become even more complicated if we consider that the survival of new seedlings of many of these species, like, for instance, the Holm oak, depends on finding conditions in which they are not excessively exposed to radiation, especially in the initial stages. If tree cover decreases much, as a result of climatic change, the areas in which the seedlings can become established may also decrease.

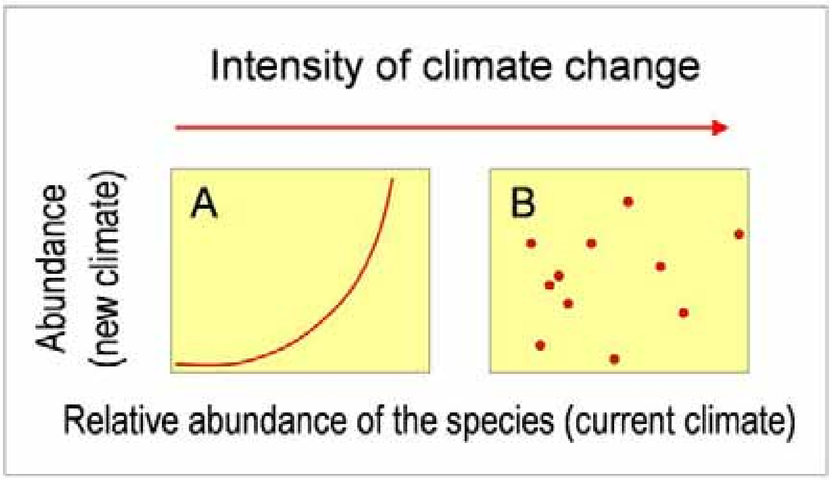

Fig. 2.6. *Effects of climate change on the diversity of seedlings in experimental simulations of drought and temperature increase in Mediterranean shrublands in El Garraf (Barcelona). The results after four years indicate that when climate change is moderate (A) the most abundant species in the present climatic conditions have more chance of survival than those less abundant, giving rise to a foreseeable impoverishment of communities, whereas when the change is more extreme (B) there is no relationship between abundance in the present climate and abundance in new climatic conditions (After Lloret et al. 2004).*

The studies based on rainfall reduction and passive nocturnal warming of the ecosystems reveal that the magnitude of the response to warming and drought is very different depending on the conditions of the study area. Cold and humid places, like Northern Europe, are more sensitive to warming, whereas our county, hotter and drier, is more sensitive to drought. It also depends on the season of the year: the processes are more sensitive to warming in winter than in summer, and once again, the responses also depend on the species, and even on the individuals (Peñuelas *et al.* 2004b). Drought will also have similar impacts on grasslands and herbaceous communities in general, in which the seasonality of rainfall is as important, if not more, than the amount of rain that falls in the year. It has been observed that drought, particularly in autumn, conditions the differential germination of species and leads to the impoverishment of grassland species, with similar effects in communities in different successional stages and topographic situations (Espigares and Peco 1995, Figueroa and Davy

1981). Modelling of tendencies and fluctuations in the diversity of Mediterranean annual herbaceous communities reveal that, although 33% of the species show successional behaviour, the vast majority respond to the temporal heterogeneity associated with rainfall, and to the spatial heterogeneity generated by the topography (Peco *et al.* 1998). The subalpine meadows in the Pyrenees will also be affected by climatic change. Recent studies reveal that warming impoverishes these communities, altering their function and inter-species competitive relationships, favouring changes in dominance and an increase in aerial, as opposed to subterranean, productivity (Sebastiá *et al.* 2004).

2.3.4. Maladjustment in biogeochemical cycles and in the hydric reserves of the soil

In spite of the fact that in the short term, drought retards the decomposition of the forest litter, its composition was not affected in the long term in experiments using rainfall reduction and passive nocturnal warming. The changes in temperature and humidity not only altered the carbon cycles, but also the N cycles and energy balances (Peñuelas *et al.* 2004b). The most complete simulations of the effects of climate change in Spanish forest systems were carried out in Mediterranean formations (mainly Holm oak forests) In Catalonia, with structural information on the forest obtained from the Catalonian Ecology and Forest Inventory (Gracia *et al.* 2000). In simulations for the next forty years, the net production of the ecosystem will vary little, in spite of the fact that there will be a considerable increase in its components (gross production in the year 2040 will increase by 56% compared with the present, and total respiration will increase by 58%). The increase in litter production, by 84%, contributes to the increase in respiration, partly as a consequence of the reduction of the average life of the leaves of evergreens, which will change from the current value of 2.6 years to a value of 1.9 years in the year 2040. These phenological changes involve important physiological change and, in particular, an increase in annual transpiration. As a consequence, the hydric reserve in forest soils, which is now 32 mm (l/m^2) if we consider the annual average at each point, drops to only 24 mm, which represents a decrease of 25% of hydric reserve; this is particularly critical in an environment with a summer hydric deficit, like the Mediterranean region at present. In spite of what has been revealed by eco-physiological studies at leaf level, the whole ecosystem's efficiency in the use of water diminishes with hydric stress, mainly due to the fact that decreases in carbon gain by around 90% during drought, as has been determined in different European Holm oak forests (Reichstein *et al.* 2002).

2.3.5. Decrease in the capacity for carbon sequestration

The estimation of the carbon balance of shrublands and forests becomes more complex due to the effect of drought, which radically alters diverse eco-physiologial processes and functions of the canopy. Experimentally induced droughts in Holm oak forests have shown that under more arid conditions than the current ones, Mediterranean forest will reduce to a great extent their growth rates and therefore, their capacity to sequestrate atmospheric carbon (Ogaya and Peñuelas 2003). In spite of the existing uncertainties, it seems clear that the efficiency in the use of water of Mediterranean forests will decrease with drought and that the carbon balance will tend to become positive (the forest becomes a source of CO_2 once again) not only in summer, but also in hot, dry years (Gracia *et al.* 2001, Joffre *et al.* 2001, Reichstein *et al.* 2002). Given the important role of the hydric and thermal conditions of the soil in the ecosystem's respiration, the net carbon balance during the dry periods will depend on the duration and intensity of the drought and on the amount of water available for the tree roots in the deep strata of the soil (Pereira *et al.* 2002). The results of the simulation of carbon balance in scenarios of climate change in the forests of Catalonia reveal that the role they play as the carbon sinks of our forest formations may be seriously threatened in the next few decades (see Chapter 9, Forestry Sector). But not only forests sequestrate carbon. Although forests have the greatest capacity to store carbon in their aerial parts, other formations, like grasslands, have great capacity to store carbon in their subterranean parts. In the case of the grasslands in the Pyrenees, it has been shown that the abandonment of traditional practices leads in a decrease in their capacity to sequestrate and store carbon (Casals *et al*. 2004).

2.3.6. Increased impact of disturbances

Disturbances, whether they be chronic or episodic, will have an increasing impact due to the fact that they will occur in ecosystems subjected to stress by climatic change. The higher frequency of episodic disturbance, like intense droughts, in combination with chronic disturbances, such as herbivory, will probably exacerbate the degradation of Mediterranean vegetation and accelerate erosion processes (Zamora *et al.* 2004). The disturbance for which most information is available and for which most models and predictions have been made on the Iberian Peninsula is fire. The climatic evolution towards hotter and more arid extremes, with an increases in biomass and in inflammability in response to the increase in CO_2, together with the abandonment of crop fields, forestation and the accumulation of fuel, will increase the intensity and, above all, the frequency of fires, restructuring the carbon balance (Peñuelas 1996). The capacity of plant species to respond to these changes in the regime of fires will determine to a great extent the alteration of the structure of the ecosystems and their response pattern to changes in climate and in the regime of disturbances. Although it could be said that many Mediterranean communities and plants are resistant to severe disturbances like fire or clearing (Cruz *et al.* 2003, Calvo *et al.* 2002), the capacity of the plants to respond varies greatly according to the type and duration of the fire, the basic type of regeneration of the constituting species (e.g. resprouters versus germinaters, Ojeda 2001) or the level of resistance of the individuals (resprouting species) and/or populations (germinating species) to very frequent fires or fires followed by stress from excessive herbivory (Ojeda 2001). Thus, an alteration in the regime of disturbance frequency could cause drastic changes in the composition and structure of communities that are apparently resistant to disturbances, as, apparently, has happened in oaks (formations of *Quercus pyrenaica*, a resprouting species (Luis-Calabuig *et al.* 2000) in the Duero basin, and as has been established through the experimental increase in the frequency of fires (Calvo *et al.* 2002). In general terms, the increase in the frequency of fires will increase the spread of purely germinating species and heliophilous ones, intolerant to shade, like the rock rose (Luis-Calabuig *et al.* 2000) and will reduce the presence of shade-loving species, forcing the communities into early successional stages (Terradas 1996). In short, although some Mediterranean plant communities may have evolved in the presence of recurring fires as a selective pressure, to the extent that fire has become an inherent element in the system, the increase in the frequency of fires as a consequence of climate change will have negative and drastic consequences for the biodiversity and structure of these communities (see chapter 12).

2.3.7. Increasing impact of extreme events

Extreme climatic events are difficult to predict, but are very important, as their ecological and evolutionary impact is very great (Gutschick and BassiriRad 2003). Both extreme droughts and heat waves have profound effects on ecosystems which are felt for years (Peñuelas *et al.* 2000, Groom *et al.* 2004). A recent review showed that extreme events are the ones that determine the evolution of many species through directional selection, and that the functional characteristics selected are not only those that provide tolerance to extreme events, but also those that optimise the harnessing and utilisation of resources (Gutschick and BassiriRad 2003). The concept of extreme event should, however, be contemplated from the point of view of organism, including the functional features and capacity for acclimatisation of this, and not from the environmental point of view, only considering the statistical rarity of a determined climatic event. Which means to say that, one same heat wave may have a notable impact on an organism that is active but not acclimatised to heat and a minimum impact on an organism in the resistance phase which is well acclimatised because this event was preceded by a period of progressive warming. The recurrence of extreme events (droughts and heat waves) has an accumulative effect, reaching threshold situations after which the impact of climate is disproportionately high.

2.3.8. Impact on the terrestrial ecosystems of islands

Climate change will have a foreseeably greater impact on island ecosystems than on their continental equivalents due to the limitation of regeneration and natural colonisation imposed by isolation. The aforementioned impacts on the tree and shrub ecosystems of the Mediterranean region can be applied to islands like the Balearic isles, but taking into account this multiplying effect due to isolation, which is directly proportional to the distance from the continent and inversely proportional to the size of the island. The Canary Isles maintain much of the current vegetation because of the Trade Winds which bring humidity and are trapped by the mountains on the islands with greater altitudes like Tenerife, Gran Canaria, La Palma and La Gomera. Climate change could compromise formations like cloud forests which are sustained by this orographic phenomenon involving the harnessing of humidity. Recent studies, however, reveal that the tendencies observed and the emerging predictions are contrary to what was expected: low clouds are increasing in frequency, which means that the potential area for cloud forest is spreading to lower altitudes (Sperling *et al.* 2004). Nevertheless, given that the low zones are densely populated, it is unlikely that the cloud forest will spread. The invasive species are particularly problematic in Spanish island ecosystems (Vilà and Muñoz 1999) and climate change could favour the spread of some of these (Dukes and Mooney 1999).

2.3.9. Corollary: predicting the unpredictable

Simulations of climate change in plants reveal big differences according to the functional group the species belongs to (Fig. 2.7). Both the natural climatic variability and that resulting from climatic change, along with the climate change itself, simulated as a scenario of a 25% reduction of rainfall and an increase in 4 ^oC, had effects that ranged from zero to very intense, depending on whether it was a Mediterranean sclerophyllous species (*Quercus coccifera*), a chamaephyte (*Thymus vulgaris*) or a perennial tussock grass (*Stipa tenacissima*), and these effects also depended on whether the response variable was reproductive biomass, leaf area index (LAI) or growth period (Fig. 2.7). Climate change *per se* and the climatic variability associated with this change had negative effects on the growth period of *Q. coccifera* whereas this parameter was hardly affected in the other species. The opposite occurred with LAI, which was barely affected in *Q. coccifera* whereas it varied greatly in *S. tenacissima*. Climate change had a very intense potential effect, reducing the reproductive biomass in *Thymus vulgaris* (Mulligan *et al.* 2004). However, the shortening of the growth period of two of the species contrasts with the phenological observations obtained for different species of trees and shrubs for which data are available (Peñuelas *et al.* 2002). These simulations, however, suggest profound effects of climate change in the plant component of ecosystems, effects which are manifested differentially in reproduction, eco-physiology or growth, and which depend on the species.

But in natural systems, the species are not alone. The complexity of effects and interactions between climate change and ecosystem processes makes it very difficult to predict the sense and intensity of the responses of terrestrial ecosystems to climatic change, although all the studies indicate that there will be important effects. What is certain is that any predictions of the conditions of Spanish terrestrial ecosystems in future decades requires better knowledge of their responses to climate change and of regionalised predictions of climate and land uses. This is still far from being available due to the inherent variability and unpredictability of the climatic system at regional level, and especially in the Mediterranean region. It must be remembered that it is very unlikely that the changes and responses will be simple linear ones. With the combination of climate change and changes in land use, we can predict that in coming decades there will be more ecosystems in early successional stages and with less ecological complexity. The decreases in plant productivity and in reproduction in response to drought (and to a lesser extent, also to warming) will be seen in a decrease in organic matter reaching the soil, and also in the recruitment of new plants and in soil cover, all of these phenomena that reduce its capacity to retain water. If the water content of the soil diminishes, plant productivity decreases, reducing even more the entry of organic matter in a vicious circle which feeds on itself (Peñuelas *et al.* 2003). Decreased water in the soil increases the risk of fire and decreased plant cover and organic matter in the soil also increase the risk of erosion.

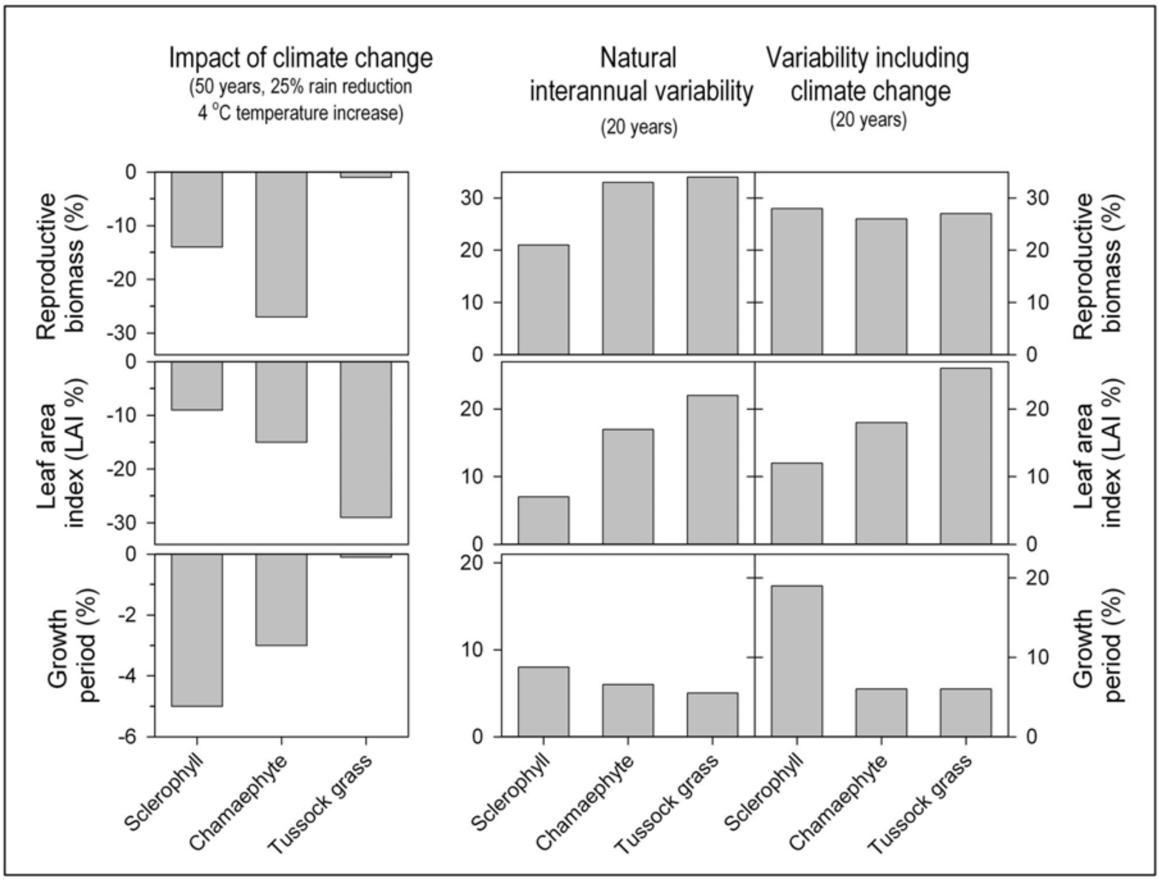

Fig. 2.7. *Impact of a simulated climate change (0.5% reduction of annual rainfall and annual increase of 0.08 ºC for 50 years) in reproductive biomass (Kg m-2), leaf area index (LAI, m2 m-2) and growth period (months year-1) in three plant species (Quercus coccifera – sclerophyll plant-, Thymus vulgaris – chamaephyte-, and Stipa tenacisima –perennial herbaceous-). The three graphs on the right show the effect of the natural inter-annual climatic variability and the variability including the climate change in a period of 20 years for these same parameters and species. The impact of climate change differs significantly among species with different forms of growth, although in general it provokes a decrease in reproductive biomass, in leaf area and in the duration of the growth period. The influence of climate change on inter-annual variability was also different among parameters and species, tending to cause an increase in the variability of the leaf area but a decrease invariability in the reproductive biomass; with climate change there is a noteworthy increase in variability in the duration of the growth period of the sclerophylous shrub. The values are expressed as a percentage and were calculated with the PATTERN model from the climatic data from the period 1940-1990 from La Alberca de Záncara and with the conditions and parameters recorded in Belmonte (Cuenca). (Data based on the tables in Mulligan et al. 2004).*

The more arid the area considered, the longer the vegetation takes to recover after multiple and prolonged droughts and/or fires, both because it takes a long time to create new biomass and because the soil often becomes degraded, especially if there is overexploitation during the dry periods or if there is a recurrence of the fires. Erosion is thus facilitated and, in extreme cases, desertification can occur, a problem that already exists in which the soils of the degraded ecosystems are incapable of retaining the water provided by the occasional storms and autumn extremes, which provoke flooding and more erosion. In areas with terracing for agriculture, erosion probably constitutes a less immediate threat than in similar areas without terracing. The burnt areas of the Levante are more susceptible to erosion because many of them are located in fields generally upon marlaceous substrates which are very sensitive to erosion, and where rainfall is limited (350–600 mm, or less) and mainly concentrated in autumn, and where, given the previous agricultural use, there is a lower number of resprouting species. These conditions would aggravate the direct conditions of the drought and would create more arid conditions in the ecosystem. The attraction of these systems for recreational activities like, for instance, the observation of nature or hunting could diminish, along with the amount of stored and absorbed carbon. This means that there could be a profound alteration of the goods and services provided by the ecosystems.

In order to lend a dimension to the role of climate change in terrestrial ecosystems, it is important to remember that all the changes described in the last few decades occurred in conditions of warming that were only a third or less of that predicted for the end of the 21st century.

2.4. MOST VULNERABLE AREAS

The Spanish areas and terrestrial ecosystems most vulnerable to climate change are the ecotones or contact areas between two or more systems, and islands in the broad sense (including isolated ecosystems like edaphic islands -–gypsums, serpentine soils and brine basins especially-, and high-mountain areas; (see section 2.2.11 for the vulnerability of island ecosystems). Logically, not all the species of a determined ecosystem are equally vulnerable. In studies of high-altitude grasslands in the Pyrenees of Catalonia, it has been observed that the boreo-alpine components are the ones most affected by warming (Sebastiá *et al*. 2004). The ecotones are vulnerable due to their great sensitivity to environmental conditions, although more than the ecotone itself, what is vulnerable to climate change is its geographic or topographic location. Given the fragmentation of the territory, however, any climatic tension applied to an ecotone cannot be alleviated by merely transferring it to other areas, as this mobility is very restricted in practice. Among ecotones, the lower limit of the forest, determined by aridity, is where the effects of climate change will be felt most rapidly. The responses observed at the upper altitudinal limit of the forest in the Pyrenees suggest that certain variables like recruitment or radial or longitudinal growth are more sensitive indicators of climate change than the altitudinal position of the forest limit (Camarero and Gutiérrez 2004). The variables to be measured in the ecotones should therefore be evaluated with care in order to detect climatic effects. The contact zones between biogeographic regions, particularly the transition zone between the Mediterranean region and the Atlantic or Eurosiberian, would also be affected very rapidly by climatic change, which would increase the area of the former at the expense of the latter. The oaks of *Quercus pyrenaica* would spread at the expense of oak forests and Atlantic forests, and the isolated fragments of the latter remaining dispersed throughout the Central System (Peña de Francia, Gredos, Guadarrama) would tend to disappear. The transitions between shrublands and Holm oak forests would undergo an analogous spread of the former at the expense of the latter.

Whereas the ecotones will generally suffer gradual changes, the island ecosystems and the riparian ones will most likely undergo brusque changes, or threshold-type changes. In the case of islands, the threshold will be determined by the minimum area, whereas in riparian ecosystems, this will be determined by flow or minimum phreatic level. Below these minimum thresholds, the ecosystems risk collapse, whereas above them, they might hardly show the effects of climatic change.

The different reviews by D.M. Richardson, P. W. Rundel, B.B. Lamont, among others, on the ecology of Mediterranean ecosystems in a scenario of global change appearing in the book by Arianoutsou and Papanastasis (2004) indicates that, contrary to what might be expected, Mediterranean ecosystems are very sensitive to climatic change. Decreased predictability of rainfall (estimated as the opposite to the seasonal or annual variance in rainfall) is reducing the diversity and the regeneration of determined Mediterranean ecosystems. Changes in the regime of fires (frequency and intensity) together with general climatic changes are already having profound consequences for these ecosystems and affect mostly strictly pyrophilous species (e.g. serotinal species) which only recruit after fire. Recent analyses of the fire regime in Mediterranean Spain have revealed that the increase in frequency and area burnt is associated with climate, so that the fires are bigger and more frequent in years of dry summers, and that rainy summers generate bigger amounts of fuel, giving rise to more catastrophic fires after two years on average (Pausas 2004).

2.5. MAIN ADAPTATIONAL OPTIONS

2.5.1. Actions involving keystone species

Evidence from diverse studies coincide in highlighting the progressive decline of keystone species in our terrestrial ecosystems, like, for instance, the Holm oak. The sensitivity observed in the Holm oak to climate change lies in its mediocre eco-physiological tolerance to severe droughts (Joffre *et al.* 2001, Martinez-Vilalta *et al.* 2002a), its poor efficiency in relation to water use during drought (Reichstein *et al.* 2002), the ageing of the masses of Holm oak and of the underwoods which are not managed through thinning and prunings, the episodes of “drought” of the Holm oak, the negative carbon balance during the summer, the long regeneration period of over 20 years of the carbohydrates used in resprouting after fire (Gracia *et al.* 1997, Gracia *et al.* 2001), and the results of Ogaya and Peñuelas (2003, 2003) which suggest the low level of competitiveness of this species in conditions of intense drought. This gradual hydric crisis can now undoubtedly be verified in some Holm oak forests, and also in pine forests and other Mediterranean forests, which are at their hydric limit, with evapotranspiration rates equal to those of rainfall (Peñuelas 2001).

In these forests, the worsening of aridity in the summer, together with unfavourable climatic periods, may be the main cause, or at least an important factor, of the mass decay of the forests. The recovery and application of the basic aspects of management of Mediterranean shrubland and forests, along with the implementation of new forestry techniques aimed at improving the efficiency of water use both of individual stands and of the ecosystem in general, are the main measures available for correcting the general downward and for preventing brusque, threshold-type responses to the increase in aridity and in the irregularity of rainfall (Gracia *et al.* 1997, Gracia *et al.* 2001, Joffre *et al.* 2001). The same type of analysis should be applied to other keystone species of our ecosystems, more example of which are provided in other chapters. However, actions involving one single species are quite inefficient if what we want is to conserve more than this determined species. In many cases, even for the conservation of this species, it is necessary to regenerate or conserve the environmental conditions that allow for its existence and the measures should be therefore taken at the level of the ecosystem, provided that this is possible.

2.5.2. Actions involving key systems

An important aspect in the attenuation of the impacts of climate change is to avail of suitable registers of the evolution of the different ecosystems over the years. But habitat loss confuses the effects of climatic change. It must be kept in mind that this loss of habitats gives rise to rapid changes in the distribution of frequencies of environmental conditions, both due to biophysical changes in the habitat and to the effects of sampling (Pyke 2004). These sampling effects are due to the fact that habitat loss is rarely random, so that the habitats that remain are a biased sample of the region's climatic conditions. Through the follow-up of these biased samples, one can overestimate or underestimate the effect of climate change if the samples are in the hotter and drier parts of the region, or in the fresher ones and wetlands, respectively. Thus, it is necessary to consider climatically underrepresented zones in the follow-up of any action, and to compensate for the tendency to protect and study small areas, unrepresentative of the general environmental conditions of a region.

There is a range of systems that merit particular attention, either because of the key role they play in the supply of goods and services or because of their endemic and relictic nature. These systems require actions to counteract the effects of climate change and to apply effective conservation therein. Among these we can highlight:

- Relictic forest formations from past climates (e.g. cloud forests of the Canary Isles, forests of *Rhododendron ponticum* in the "canutos" of Cádiz and Málaga, forests of *Prunus lusitanica* in Extremadura)
- Tree or shrub formations in arid areas like those presenting *Maytenus senegalensis, Ziziphus lotus, Tetraclinis articulata,* and *Whitania frustecens.*
- Fragmented or isolated formations like the birch forests and beech forests in central Spain, the yew forests, holly forests and isolated woods of conifers like *Pinus sylvestris* in Sierra Nevada, *P. uncinata* in the Iberian System, *Abies alba* in Montseny and those of *Abies pinsapo* in the Serranía de Ronda.
- The aforementioned vulnerable areas (ecotones, island and high-mountain systems)
- Holm oak forests and *dehesas* of Holm oak showing signs of poor regeneration and vulnerability to climatic change.

2.5.3. Integrated design of protected natural spaces

The design of new protected spaces and the restructuring of the existing ones should incorporate the concepts dealt with here, which in short would include good representation of both the size and the spatial distribution of the main ecosystems of a region, and would allow for the migration and for changes in the distribution of species and systems through the inclusion of altitudinal gradients and biological corridors between the different zones. More emphasis must be placed on the management of the environment in the broad sense, because the protected spaces may become obsolete, and the systems or species to be conserved or protected or may change or disappear, especially in scenarios of climate change (Harrison *et al.* (Eds.) 2001).

2.6. REPERCUSSIONS FOR OTHER AREAS OR SECTORS

The sensitivity of many Spanish terrestrial ecosystems to climate change means that the measures taken to conserve them have repercussions in different socio-economic sectors. Some important examples are:

- Good management of hydric resources, indispensable for the maintenance of many natural formations, conflicts with intensive tourism or the facilities of golf courses in arid areas.
- The conservation of high-mountain areas is incompatible with the mass and intensive use of

the ski season.

- Intensive greenhouse crops in arid areas do not allow for the good conservation of the natural systems or for good water use.
- The management of certain areas for big game hunting leads to systems with a high level of pressure by herbivores, which are poor in species and vulnerable to climate change and disturbances.
- Forestry based on single cropping threatens the functionality of the ecosystems, as well as their long-term sustainability.

The conclusions of this chapter have clear repercussions on aspects that are dealt with in other chapters (e.g. Forestry Sector, Edaphic Resources, Animal and Plant Biodiversity, among others).

2.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

Cox *et al*. (2000) have estimated that the increase in respiration caused by temperature increases could turn many ecosystems into sources, and not sinks of CO_2 by the year 2050. The effect of drought, however, has not been taken into account, and, as Reichstein *et al*. (2002) showed, this can profoundly alter the balances of carbon and water whose calculations are based on models that only consider the stomatal response of the vegetation. In general, interactions between both factors (e.g. temperature, water and light) and between species (networks of trophic interactions, mutualisms, etc.) increase very much our uncertainty of the effects of climate change on our terrestrial ecosystems. This fact, along with the lack of long temporal series makes the predictions of the effects of climate change on these systems very fragile. Furthermore, the low level of spatial accuracy of the predictions makes the uncertainty even greater at local level, in spite of the fact that many processes operate at this level (e.g. local extinctions). The lack of information on the eco-physiology of keystone species (e.g. tolerance to drought in interaction with shade, the capacity for acclimatisation of respiration at high temperatures, the global effects of volatile organic compounds) together with the lack of genetic and molecular data makes it very difficult to calculate the capacity for evolution of the species in a changing world. Besides, it is also difficult to isolate the effects of climate change from those of the simultaneous participation of other motors of global change. In order to do so, experimentation is needed, and not only observation and follow-up. Table 2.1 summarises the level of uncertainty in relation to the main impacts that climate change will have on Spanish terrestrial ecosystems.

2.8. DETECTING THE CHANGE

The effect of climate change on terrestrial ecosystems can be detected by means of different types of indicators, ranging from the follow-up of particularly sensitive species of flora and fauna to monitoring ecosystem variables in zones of special interest. With regard to the former, specific recommendations can be found in the chapters on plant and animal biodiversity. However, we must emphasise the suitability of the population viability analyses (PVA) in order to detect the effects of climatic change. These analyses are already being carried out in the case of rare or endangered species (e.g. almost 40 species of critically endangered plants within the framework of the Atlas of Endangered Flora under the auspices of the Ministry of Environment) and are enabling the detection of effects that can be attributed to a certain extent to climate change. Here we propose a series of variables the follow-up of which has permitted and will permit us to detect the effects of climate change in the functioning of ecosystems. The variables differ with regard to their cost, both in economic terms and with regard to the technical level required, and are valued according to this cost (C, costly, E, economical, E-C the cost depends on the measurement protocol).

Table 2.1. *Level of uncertainty of the most relevant effects of climate change on terrestrial ecosystems in Spain*

Certainty	Most relevant effects of climate change on terrestrial ecosystems in Spain
****	Changes in species phenology
****	Changes in the interactions among species
****	Expansion of invasive species and pests
****	Changes in the species dominance of a community
****	Changes in the structure and functioning of terrestrial ecosystems
***	Decreased productivity due to warming and drought
***	Altitudinal migrations of keystone species
***	Decreases nutritive quality of the plants
***	Decreased capacity to sequestrate carbon
***	Local extinctions
***	Increased impact of disturbances and extreme events
**	Tolerance of new conditions through the acclimatisation and plasticity of keystone species
**	Lengthening of the real growth period of the vegetation
**	Increased emissions of VOC
*	Tolerance of new conditions through the adaptation (evolution) of keystone species
*	Latitudinal migrations of keystone species
*	Increased efficiency of water use by plants
*	Collapse of trophic networks
*	Acceleration of biogeochemical cycles due to warming and drought
*	Readjustment of the ecosystems to the new climate

(** very high certainty, *** high certainty, ** medium certainty, * low certainty)**

Phenological variables

Production of flowers and fruits of keystone species (enlargement of the Meteorology Institute list to include representative natural and wild species; E), phenology of plant communities (estimate of general dormancy moments, maximum production, maximum flowering, etc.; E), appearance of insects and migratory birds species (enlargement of the Meteorology Institute list to include representative natural and wild species; E),

Abiotic variables

Thermal changes and changes in rainfall in extreme zones, ecotones and habitats of relict species or populations or those at the limit of their distribution (E), follow-up of erosion in zones such as the previous one (C), follow-up of the phreatic level in zones like the previous one (C), follow-up of soil temperature and humidity in zones representative of the main ecosystems (E),

Structural variables

Leaf area index (LAI; E-C), accumulation of biomass and necromass (C), root development (C), altitudinal movement of ecosystems (upper and lower forest limits, ecotones, altitudinal limits of keystone species; E), dynamic cartography of ecosystems (temporal follow-up of their area and spatial distribution; C)

Ecological and physiological variables

Net carbon exchange of the ecosystem (Eddy Flux covariance technique; C), productivity (E-C), reserve carbohydrates in plant tissues (starch, mobile carbon, particularly in resprouting species; C), mineralisation of organic matter (C), natural regeneration of keystone species (C), follow-up of the rhizosphere (diversity, productivity; C), experimental simulation of warming and drought (C), emissions of volatile organic compounds (VOC; C), follow-up of populations of invasive species (E-C), follow-up of pests and pathogens (E-C).

In the case of any of the variables referred to, follow-up should include long temporal time periods, due to the marked intra- and inter-annual oscillations both of the climatic variables and of the responses of the ecosystems to environmental change. To this end, in the first place, the initiatives existing in Spain ought to be used, and before any new action is initiated, it must be ensured that no similar temporal series already exists. By way of an example, of particular strategic value is the maintenance of the phenological observations by the National Institute of Meteorology, of the forest health follow-up network (Ministry of Environment) and initiatives like the RESEL network for the physicochemical follow-up and the follow-up of soil erosion (Rojo and Sánchez-Fuster 1996) (see chapter on edaphic resources). The power of the existing initiatives is their seniority, and the series of uninterrupted data for long temporal periods should be given priority. This support of existing series should also be completed with the support of more recent initiatives and even of new initiatives to fill the big knowledge gaps or the badly recorded geographic areas. Many of these series are backed by the collaboration of different scientific groups and have certain moderate logistic requirements, which favours their continuity. Special mention should be made of the follow-up stations of the carbon balance of ecosystems by means of “Eddy flux” covariance, like the one in El Saler (Albufera Nature Park in Valencia) under the auspices of the CEAM, and the experimental facilities for the study of the effects of climate change in Montseny and El Garraf (Barcelona) belonging to the CREAF. Unlike the aforementioned initiatives, these facilities are costly, but the information they provide is of great value. In order for these facilities to be valued, and for the information they provide to detect the effects of climate change in terrestrial ecosystems, it is not sufficient to keep them active for long periods of time, but rather they should be integrated into other networks in order to compare results with other systems (e.g. shrublands, grasslands) and with other regions.

2.9. IMPLICATIONS FOR POLICIES

2.9.1. The importance of social awareness

The introduction of multi-use strategies for the management and rehabilitation of terrestrial ecosystems requires much education and research, and effort by the government, too, in order to give hope to the future development of these terrestrial ecosystems and of their resources within the framework of current climate change and land uses. In order to inform the public in general of the problems related to climate change and its effects and interactions with terrestrial ecosystems, we have phenological change as an easy-to-use and popular tool which shows everyone how climate change can affect our lives. Use should also be made of events like the 1994 drought in order to make the public aware of the of water reduction on our ecosystems. In these terms, and in all those terms previously referred to, all the research activity should be disseminated through the media. The communication activities should also be supported, with the joint participation of the stakeholders involved in research and in the forest management of natural spaces.

2.9.2. Sustainable management of ecosystems, reforestation and ecological restoration

Management of terrestrial ecosystems and planning the type and intensity of human activity should be based on a balance between the global vision of ecosystem processes, regional knowledge and local action. The dynamics of our ecosystems, almost all of them semi-natural ones, can be understood as a series of anthropogenic degradations and subsequent regeneration. Indeed, both overexploitation and complete protection can lead to lower levels of scenic attractiveness and economic utility in many terrestrial ecosystems like Mediterranean forests and shrublands. These current Mediterranean formations cannot be understood without human intervention, and an obvious paradigm is constituted by savannah or *dehesa* systems. Although changes in climate and in the regime of fires and disturbances could mean that the *dehesas* are maintained through measures different from human uses, at present, both the *dehesas* and the diversity they contain depend on correct forest and livestock farming management (Díaz *et al.* 2003). The management of these systems involves the management of high levels of biological diversity, and although in themselves, they may not contribute to the sustainability of the system, they may very well contribute to its maintenance and conservation thanks to value given by society to these systems, which are rich in species (Blondel and Aronson 1995). In spite of the fact that the need for human intervention has been demonstrated in order to maintain the local coexistence between grasslands and forests in the *dehesa,* the processes and mechanisms have not yet been established through which human intervention can be seen as important for the maintenance of this coexistence (Marañón *et al.* 1999). The management of these systems should therefore be adaptational, and should be able to vary according to the evolution of the system and to the effects of the management applied in each case (Rojas 2001, Charco 2002, Valladares 2004b).

There is abundant evidence that in actions aimed at rehabilitating or restoring terrestrial ecosystems, the optimum action lies in helping nature to recover, accelerating the natural processes of ecological succession, and minimising intervention (Suding *et al.* 2004). These actions should consider the tendency towards climatic change, and not just apply classical protocols, adjusted to the predominant climatic conditions to date. Knowledge of the mechanisms of the ecosystems' resistance to stress enables us to understand the evolutionary processes involved in the adaptation of the different species to environmental changes and to predict, to a certain extent, their response to the increase in adversity associated with global change (Valladares 2004b). This knowledge should be incorporated into the restoration programmes, for instance by improving or selecting the characteristics of the plants to be used in reforestation or restoration projects. Knowledge of these mechanisms may also enable us to use sensitive species as bioindicators of the stress associated with climatic change.

The people managing our nature and our habitats, both rural and urban, should consider the properties related to the emission of volatile organic compounds by the different plant species if they aim to avoid the formation of secondary atmospheric pollutants. Indeed, while they must consider the high-emission species as candidates for the reforestation of arid zones with high temperatures, as they are the ones most resistant to these conditions, they will have to chose the species with the lowest emissions for the reforestation of urban and suburban areas, as well as industrial areas, subjected to high levels of anthropogenic pollution (for instance nitrous oxides) if they are to avoid the formation of secondary pollutants like ozone. With the current ecological and climatic information referring to the Mediterranean coasts, the correct reforestation of the slopes of these coastal mountains could be used to reactivate the trigger and feedback mechanisms of summer storms, thus guiding the system towards a configuration with more vegetation, stabilising some of the anticipated effects of climate change (Millán 2002). This could also be applied to other areas in which the vegetation significantly affects the local characteristics of the atmosphere. In short, the forest management of natural spaces must not ignore the role of forests and shrublands in the preservation of the atmosphere and as buffers against polluting environments rich in $CO_{2.}$

2.9.3. Carbon sequestration versus the biological diversity and functionality of ecosystems against desertification

The management of terrestrial ecosystems ought to consider the important role played by the emissions of gasses by plants in atmospheric chemistry and in local and global climate, and the role of plants as sinks of such important atmospheric gasses as $CO_{2.}$ In order to mitigate climate change by greater harnessing and less loss of CO_2 forestation and reforestation can be used, with the aim in mind of lengthening the immobilisation of carbon in forest products and of protecting the soils. Forest management will also have to incorporate the change in environmental conditions at the moment of defining the intensity and frequency of interventions. For example, if we take into account the increasing conditions of drought, we will have to reduce the density of shoots in high-density forests, a strategy which has proven to be effective for reducing the impact of extreme droughts.

Almost 90% of carbon in the form of biomass is accumulated by forests, which is 50% of terrestrial organic carbon. However, Körner (2003) observed the temporal asymmetry caused by the slow growth of a tree and the brusqueness of the disturbances (fire, logging, herbivory, decay) which release a lot of carbon into the atmosphere. In the case of underwoods of Holm oak and oak, dominant in many parts of the Iberian Peninsula, industrialisation and rural depopulation led to a brusque change. The traditional use of these forests for timber and charcoal has been abandoned, with much longer periods between clear cuts. These aged underwoods show very slow growth, which may imply greater vulnerability to the effect of abiotic stresses (e.g. drought) or biotic ones (e.g. defoliating pests). An experiment carried out at small scale (Luis-Calabuig *et al.* 2000) attempted to determine if the thinning of the underwoods favoured the development of the tree shape of the oak (*Quercus pyrenaica*) from dense and continuous shrub formations promoted by repeated fires. No differences were observed in the growth of the oaks between the treatments applied to eliminate the shrubland and the original situation. In the thinning, however, we observed that an increase in trunk perimeter was favoured over the growth in height of the 10 shoots that remained, the competition for light having diminished. With more long-term treatment it would be possible to improve the structure of these ecosystems. The intense disturbance associate with traditional forestry treatments causes a rapid release of carbon, but if no treatment is applied, there is a risk that the poor growth rate of these aged forests and their greater vulnerability to stress situations may lead to an acute decay and a high death rate, and, once again, provoke the abrupt release of carbon. This paradox is currently insoluble due to our ignorance of the functioning of the underwoods, and poses serious doubts about the role of these formations of *Quercus* species as carbon sinks.

In general, the policies and actions aimed at increasing the sequestration of atmospheric carbon by vegetation are incompatible with the conservation of biodiversity or the sustainable exploitation of this. One of the few compatible solutions identified to date would be to select unproductive areas for the maintenance of high-biodiversity forests and formations capable of storing the sequestered carbon over long periods of time, and to use more productive areas for other uses (Huston and Marland 2003).

2.9.4. Nature conservation and protected natural spaces

Palaeoecological models establish that the main centres of European postglacial dispersion were the southern Iberian Peninsula, Italy and the Balkans (Willis and Whittaker 2000). Therefore, if a species of tree becomes extinct from southern Europe, the chance of continental extinction in the face of future climatic changes are much greater if the extinction affects the British Isles or Scandinavia (Carrión 2003). This is a solid argument to insist, both at national and community levels, on the conservation of our terrestrial ecosystems and the application of sustainable development policies.

With the foreseen climatic change, the vegetation could spread to the higher mountain zones, but the communities already existing in these high zones will become extinct (Peñuelas and Boada 2003). In many cases, the only migration possible is towards northern latitudes. But the migration rates would not be efficient in the current scenario of global change, as, on one hand, the climate changes too quickly, and, on the other, the territory is very fragmented, which significantly restricts the real possibility of latitudinal or altitudinal migrations by the vegetation. For this reason, when managing the protected natural spaces or selecting new spaces to be protected, it is necessary to maximise the connectivity between the different units and ecosystems in the zone in order to compensate for fragmentation. Besides, it is important to conserve processes and systems, and to establish suitable spatial scales for the ecological processes. In order to ensure efficient long-term conservation of many of these processes, we must incorporate zones with different levels and types of human intervention and with different levels of susceptibility to climatic change. The protected natural spaces should establish a “risk reserve”, a component created specifically to reduce the ecological risk associated with climatic change. Furthermore, the management of natural spaces should incorporate a landscape scale that contemplates the combination of different types of spaces, favouring a multiple and controlled use, but without suppressing the effect of disturbances like fire.

2.9.5. Need for co-ordination and a closer relationship between research and follow-up

It is necessary to bring together the organisms, institutions and human and technological teams dedicated to the follow-up of environmental change, along with those dedicated to research into its effects on terrestrial ecosystems. It is only possible to obtain reliable results related to these effects through scientifically rigorous analysis of very diverse data, resulting from a necessarily interdisciplinary approach, and this analysis is only feasible if these data (environmental, ecological, physiological, etc.) are collected and stored in an equally rigorous manner over long periods of time.

2.9.6. Corollary: the funding of the goods and services provided by ecosystems requires creativity and flexibility of policies for greater social compromise

Climate change will exacerbate in a foreseeable way the environmental crisis the nature of our country is undergoing in general terms, and the terrestrial ecosystems in particular. One of the main causes underlying the poor sustainability of the current management of Spanish terrestrial ecosystems is the unprofitability of many of them. When ecosystems are not profitable, no investment is made in them. And it makes no difference whether they are publicly or privately owned, as the surface area of terrestrial ecosystems is so great that not even the State manages them if a minimum level of profitability is not ensured. This is evident in the case of forest ecosystems, for which European policies are dominated by the timber-producing countries, whereas Mediterranean forests, in spite of their considerable area, are considered as marginal. Thus, Spain is the European country with the highest proportion of economically unproductive forest, due, on one hand, to the abundance of unprofitable shrublands, above all in the areas with a dry Mediterranean climate, and on the other, to the existence of protected spaces. Society at present, however, assigns to terrestrial ecosystems a series of functions which surpass by far mere production, and increasing value is being given not only to hydrological regulation and protection against erosion, but also to the recreational use, the conservation of biodiversity and landscape and carbon storage. All of these functions mean that society recognises the benefits provided by terrestrial ecosystems, although they do not provide direct economic ones. As the owners do not receive any income from these services, there are no sources of finance to invest in the social functions of the ecosystems. The scientists do not have the answer to this kind of problem, but the correction of the malfunctions that will be accentuated by climate change will only be made if the funding problem is solved. The administrations should therefore use their imagination to find new sources of resources. If the ecosystem provides services, these should somehow be paid for by the beneficiaries (sometimes society as a whole, sometimes specific groups or private individuals). If the forest produces clean water, the societies supplied by this water and the municipal authorities ought to become involved in forest management. If it used for conduits, so should the electricity companies. The same can be said of the housing estates, hotels and other tourism establishments making use of the landscape. Social involvement is needed to develop new forms of management, in accordance with the newly recognised services provided by terrestrial ecosystems (Peñuelas *et al.* 2004a). The solution cannot come from the economy of administrations or from the efforts of a few private owners, but rather from imaginative and flexible policies involving greater collective compromise in order for the ecosystems to be treated in accordance with the services they provide us with and with their intrinsic value.

2.10. MAIN RESEARCH NEEDS

New ecological studies constantly reveal new patterns, and modification and exceptions to the known responses of species and terrestrial ecosystems to increasing drought and warming. This shows that our knowledge is still very little and possibly insufficient to satisfy the urgent need for accurate predictions and recommendations for the management of terrestrial ecosystems in a changing world. From the vast amount of knowledge needs seen in this review, we have established the following main lines of research, which need to be reinforced:

1. Attainment of long temporal series in order to establish tendencies and to analyse the dynamics of responses and reactions. The long-term follow-up of ecosystems will enable us to detect:
    a. The physical bases of environmental change itself,
    b. The impact of climate change on the ecosystems,
    c. The results of the attempts to mitigate climate change and its effects.
2. Study of the interaction between climate change and changes in land uses. Development of experiments and manipulation to separate the effects of both factors.
3. Study of the interactions between climatic factors (temperature, light, water, CO_2) and their effects on ecosystems.
4. Study of the interactions between species and of the sensitivity of networks of interactions to climatic change.
5. Extension of ecological and ecophysiological studies to unknown ecosystems, not only those dominated by unique species (see section 12.5.2), but also Mediterranean Holm oak forests and shrublands situated outside Eastern Spain (e.g. moorlands and continental zones, high mountain).
6. Analysis of the indirect effects of climatic change. Cascade effects. Synergic reactions and autocatalytic cycles like, for example, the decrease in productivity, the increased attacks by pests and the rising risk of fire.
7. Analysis of the expression time lag of the effects, of the reaction by the ecosystems and of the adaptation and evolution in new scenarios.
8. Selection of early indicators of change.
9. Determination of minimum tolerance values (minimum area, minimum hydric availability, minimum size and structure of the network of interspecific interactions) in vulnerable systems, particularly in those with a propensity for threshold-type responses, like island and riparian ecosystems.
10. Effects of climate change on the spread of invasive species.
11. Study of subterranean processes (C sinks, dynamics of roots and edaphic microorganisms).
12. Implementation of complete carbon balances for the different terrestrial ecosystems through the optimisation and parameterisation of accurate models and estimates, not only of biomass (aerial and subterranean), but also of necromass.
13. Improvement of ecological restoration techniques for the recovery of plant cover and other functions and services of ecosystems in degraded areas.

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3. IMPACTS ON INLAND AQUATIC ECOSYSTEMS

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ABSTRACT

Spanish inland aquatic ecosystems (SIAE) are very diverse, generally of a small size, are located in very large watershed, often depend on groundwaters and undergo intense hydrological fluctuations, related to the local water balance, which affect their ecological functioning. Their importance on an international level derives from the fact that 1) the climatic, geologic, physiographic, hydrological and landscape characteristics of the Iberian Peninsula provide Spain with the greatest diversity of inland aquatic ecosystems in Europe; 2) there are 49 wetlands included on the list of the Ramsar Convention; 3) these are mostly environments different from the cold temperate European ones, with a multitude of endorheic sites and temporary ecosystems, as well as unique and very specific flora and fauna, some of these dating from the Tertiary Period; 4) the alpine lakes of Sierra Nevada are the southernmost glacial lakes in Europe; 5) the new European Framework Directive on Water includes them in Iberian-Macaronesian Region, and also distinguishes the Pyrenees as a region of particular interest.

With a high degree of certainty, we can state that climatic change will make many of the SIAE lose their permanence and become seasonal instead – some will even disappear. The biodiversity of many of them will decline and their biogeochemical cycles will be altered. We cannot yet determine the magnitude of these changes. The ecosystems most affected will be: endorheic environments, alpine lakes, rivers and streams (1600-2500 metres), coastal wetlands and environments depending on groundwaters.

The possibilities of the SIAE to adapt to climatic change are limited. In order to attenuate the effects, water-saving policies are needed, along with an improvement in the quality and intensification of the conservation measures of the surrounding terrestrial habitats. If we take into account the foreseeable conflicts over water resulting from climatic change, it is reasonable to suggest that the SIAE will be given the lowest priority.

The changes the SIAE are likely to undergo will affect environmental conservation and the tourism sectors, population protection and resources management, water supply and inland fisheries. With regard to the relationship between climatic change and the SIAE, there is a series of information gaps resulting from 1) a lack of reliable series of long-term data; 2) the still very scant information on the ecological state and biology of the most important species; 3) lack of knowledge of the hysteresis processes and 4) ignorance of the possible effects on the SIAE of both the geology of the watersheds in which they are located and the abrupt or gradual changes in surrounding terrestrial plant communities. All the preceding factors therefore have implications for policies for the environment, tourism, sports fishing and science. There is a great need for research, as there has been practically no treatment of the relationship between the SIAE and climatic change.

3.1. INTRODUCTION

3.1.1. The Spanish Inland Aquatic Ecosystems

The approximate number of continental aquatic ecosystems rises to over 1,000 large reservoirs (Dirección General de Obras Hidráulicas – waterworks dept. - 1988), 2500 alpine lakes bigger than 0,2 ha in the large mountain ranges (Pyrenees, Sierra Nevada, Central System, Iberian System, Cordillera Cantábrica), 50 karstic lakes in Ciudad Real, Cuenca, Girona, Huesca and Lleida, 11 large watersheds with numerous temporary and permanent river courses, over 500 lakes generated by mining (Montes 1993) and around 800 wetlands of over 0,2 ha, including shallow lakes and coastal pools (INITEC 1991; www.mma.es/conserv_nat/planes/plan_humed/plan_humed.htm).

3.1.2. The dependence on subterranean waters

Many continental aquatic environments (above all rivers, lakes and wetlands) depend on underground waters. The best example is the Las Tablas de Daimiel National Park, which became disconnected from the underground aquifer in 1986 due to overexploitation, and has since had to depend on water from another watershed to subsist. The regional and local flows of subterranean waters (Toth 1963) not only supply lakes and wetlands (Montero 2000), but also many river channels [see chapter on Hydrological Resources]. That is to say, many reaches of Spanish rivers are "winners" and that the flows and hydrochemistry upon which their ecological functioning depends are the result of the interaction between surface and underground waters (Montes 1995). In any case, the quantitative hydrological relationship between aquifers and surface waters has not been sufficiently studied in Spain to date (see Benavente and Rodríguez 1997; de Castro and Muñoz Reinoso 1997). Furthermore, the recharge of the aquifers depends on the relationship between the season of the year in which this takes place (or the number of times it occurs) and the amount of water available for the recharge (rainfall; Fetter 2001); these facts are particularly relevant in semiarid areas, found throughout much of Spain, in which the biggest recharge usually takes place following intense rainfall (Wood and Sandford 1994).

3.1.3. International importance of the Spanish continental aquatic ecosystems

This is based on the following aspects:

1) The climatic, geological, physiographic, hydrological and landscape characteristics of the Iberian Peninsula provide Spain with the greatest diversity of inland aquatic systems in Europe.

2) There are 49 wetlands included on the list of the Ramsar Convention (www.mma.es/conserv nat/acciones/humedales/html/comite/lista ramsar.htm; MIMAM 1999).

3) Most environments are different from the cold, temperate European ones, with numerous endorheic sites and fluctuating seasonal ecosystems, containing unique and very specific flora and fauna.

4) Although inland aquatic fauna are considered to be relatively recent, many wetlands contain relics from the Tertiary Period (Alonso 1998).

5) The alpine lakes in Sierra Nevada are Europe’s southernmost glacial lakes.

6) The close dependence of our inland aquatic ecosystems on subterranean waters and on their watershed surface makes them very vulnerable, and a preferential objective of the new

European Framework Directive on Water (Directive 2000/60/CE), which includes them in the Iberian-Macaronesian Region (map A, appendix XI), although it distinguishes the Pyrenees as a region of particular interest.

3.1.4. Sensitivity of the Spanish aquatic ecosystems to climate

Spanish aquatic environments are extremely sensitive to climate because the vast majority of them has a very short water residence period and therefore depend on annual, or even seasonal, rainfall. The levels and flows of most rivers, lakes, reservoirs and wetlands are directly linked to short-term rainfall. Obviously, air temperature also conditions aquatic systems by means of its direct influence on water temperature which, in turn, affects the metabolic and biogeochemical processes taking place in aquatic ecosystems (Carpenter *et al*. 1992).

Furthermore, indirect climatic influences are very important in the continental aquatic environments of the Iberian Peninsula, as these environments depend on the characteristics of the watershed they are located in, and the effects of climatic change on the soils and vegetation of the watershed would therefore have additional effects on the aquatic environments (Catalan *et al*. 2002; Comín and Alonso 1988). In general terms, the watersheds are very big in comparison to the aquatic ecosystems found therein, which are therefore very sensitive to the influence of the landscape (Prat 1995). Changes in the evapotranspiration of the terrestrial vegetation, for instance, can have a great effect on the availability of water in the watersheds (Schindler 1997), as can be seen in the study by Beguería *et al*. (2003).

3.2. SENSITIVITY TO THE PRESENT CLIMATE

In relation to climatic change, temperature and rainfall will undergo a series of variations which have not yet been clearly established [see the Chapter Climate in Spain: past, present and climate scenarios for the XXI century], and whose general effects on the inland aquatic ecosystems could be the following:

3.2.1. Effects of the changes in rainfall on water availability: averages and variability

There are two types of most likely rainfall tendencies for the future: a decrease in averages and increased variability, although there could well be relevant geographic variations [see the Chapter Climate in Spain: past, present and climate scenarios for the XXI century]; section 1.3.6]. Both phenomena have important consequences on the availability of water for the inland aquatic ecosystems, because in the long term they could make many of the temporary systems disappear and turn some the currently permanent ones into temporary ones. The increase in the variability of the rainfall would determine a greater variability in flows (Arnell *et al*. 1996). The seasonal factor, however, still remains very uncertain. The foreseeable decrease in summer rainfall may not be very positive for the inland aquatic ecosystems, as their current values are low. To the contrary, the variations in winter and spring could be determinant for environments with a propensity for temporality, both lotic (for instance, streams and torrents) and lentic ones (for example, lakes and ponds in semiarid areas).

3.2.2. Effects of global warming

Mean air temperature will also increase, probably more in the cold months and at night than in the hot months and during the day. There will therefore be an increase in water temperature, which will perhaps prolong the autumnal period of biological activity. In any case, it would be reasonable to expect modifications in the rates of the biogeochemical and metabolic processes, which might eventually lead to changes in the structure of the biological communities. It is foreseeable that the stratification of the lakes will be prolonged throughout the year (Livingstone 2003). In mountain areas, the duration of the layer of snow and of the lacustrine ice cover will be shorter, advancing the spring phases in these systems, and these changes may affect the functioning of the lake for the rest of the hot period.

3.2.3. Effects of an increase in sea level

Although a big change is not forecasted (0.11-0.77 metres up to 2100; Church *et al*. 2001), there could be more important ones in the case of coastal wetlands, because they will either be flooded and destroyed (because they do not reach very far inland), or saline invasion will increase, thus changing the nature of the wetland. In any case, there will probably be very varied effects on the coastal areas, depending on the different zones of the Iberian Peninsula [see Chapter on Coastal Zones].

3.2.4. Effects of an increase in CO_2

No significant effects from CO_2 increase are expected on the inland aquatic ecosystems. In general, the variability caused by CO_2 is less relevant than that determined by seasonal variations in nutrients and climatic factors. To a certain extent, inputs of allochthonous carbon from watersheds that are very large in comparison to the limnetic ecosystems and the total or partial oxidation therein could mean that the Spanish aquatic ecosystems are sources rather than sinks of CO_2. A better solubility of calcite in rocks and soil by CO_2-enriched rain is expected, thus producing a higher input of calcium into lakes and streams (Roland Psenner, personal communication).

3.2.5. Effects of decreased cloudiness

A reduction in cloudiness during the hot part of the summer would lead to an increase in the amount of UV radiation reaching the aquatic ecosystem, with the subsequent possible effects of photo-inhibition of photosynthesis, of metabolic alterations in plants and animals and of an increase in the photo-oxidation of dissolved organic substances (Williamson and Zagarese 1994). But in any case, it does not seem that this effect of cloudiness will be significant throughout the whole territory, as the most exposed mountain areas already contain flora and fauna which are adapted to conditions of high radiation (Halac *et al*. 1997; Sommaruga *et al*. 1999). Whatever the case may be, these effects will likely be camouflaged by other more relevant consequences of climatic change.Some alpine waters may even become better protected from UV radiation, if the treeline moves upwards(Roland Psenner, personal communication), as it is expected (see Chapters on Terrestrial ecosystems and Forestry).

3.3. FORESEEABLE IMPACTS OF CLIMATIC CHANGE

The effects of climatic change may interact with other anthropic effects resulting, for instance, from changes in land use, removal of water or rubbish dumps. On occasions, it is difficult to differentiate between these factors, but in any case, we should take into account the possible interactions between them. For instance, extraordinary flooding is not provided for in the regulation of water flows, and it seems likely that this flooding will increase along with increases in extreme events. Although defining in detail the impacts of climatic change is a difficult task, given the available current forecasts, it is not at all unreasonable to think that there will probably be an increase in the socio-economic conflicts over water. In this sense, it is important to critically consider the arguments in favour of conserving the inland aquatic environments in a country that has traditionally turned its back on these if they produced no direct profit.

3.3.1. Analysis of the Holocene sedimentation in lakes and wetlands

Throughout the history of the Earth, there have been no conditions analogous to the current increase in atmospheric CO_2, as during the last 400,000 years, in which we have had a set of species and ecosystems similar to the current ones, there have never been concentrations of this compound as high as can be reached when the present increase has been stabilised, even in the best of possible scenarios. Nevertheless, it is very probable that we will experience transitory situations of greater or lesser duration which will be similar to certain situations in our recent past. In this sense, the records of the environmental conditions throughout the Holocene (the last 10,000 years) preserved in the sediment of lakes and wetlands may provide information on the situations and rates of change to be expected. The reconstructions of variable environments based on lacustrine sediments provide references at temporal scales higher than those derived from the use of instrumental measurements (maximum of two centuries) and from historic documents (Barriendos 1997) and enables us to observe the effects of sudden climatic changes in the past, which are impossible to evaluate experimentally in specific ecosystems at the present time (Kelts and Talbot 1989; Gierlowski-Kordesch and Kelts 1994; Last and Smol 2001; Cohen 2003). In any case, the interpretation of the processes observed is related to the local geology and geography, as the responses of lakes to global changes is always very dependent on its own geologic, geographic and climatic characteristics, and those of the local physical environment.

The climatic changes that took place on the Iberian Peninsula during the Holocene had a greater impact on water balance than on temperature, although neither of these is absolutely independent (Harrison *et al*. 1992, Cheddadi *et al*. 1997; Prentice *et al*. 1998). The environmental reconstructions based on stratigraphic data from the Holocene which are of most interest are therefore those related to water balance (Fig. 3.1). The reconstructions carried out show that, between the Mediterranean and Atlantic areas of Spain, there was a hydrological gradient during the Holocene similar to the present one, and that the ecosystems of the Mediterranean zones in which the water availability was always relatively lower, reacted faster to climatic fluctuations than those situated in the areas of Atlantic influence.

Reconstructions of lacustrine environments based on data from the Holocene are highly reliable at a scale of millennia (Pérez i Obiol and Juliá 1994; Luque and Juliá 2002). Since the Neolithic, the changes in the vegetation of the terrestrial ecosystems may have had an important anthropogenic component, whereas hydrological changes originated by human activity are limited to the last few centuries (Valero Garcés *et al*. 2000a-c). Although a change in vegetation can modify the water balance due to changes in the evapotranspiration in the basins brought about by variations in tree cover, the existing reconstructions are less reliable at more detailed temporal scales. The lack of studies in the right type of lakes, the poor vertical resolutuion of the sediment cores and the financial costs of a detailed study have all limited this type of studies up to the present time (Battarbee *et al*. 2002). In spite of this, different studies show the extreme sensitivity of lacustrine systems to fluctuations resulting from oscillations in the North Atlantic, such as, for example, the 1,500 year cycles found in Sanabria (Luque and Juliá 2002) and even with teleconnections much further away, like the records of the oscillations of El Niño in Gallocanta (Rodó *et al*. 1997). There are hardly any studies at seasonal scale to analyse the past or future impact of changes in the annual distribution of rainfall. There are indications, however, that changes in wintertime rainfall have been decisive in the water balance and in changes in plant communities (Valero Garcés *et al*. 2004).

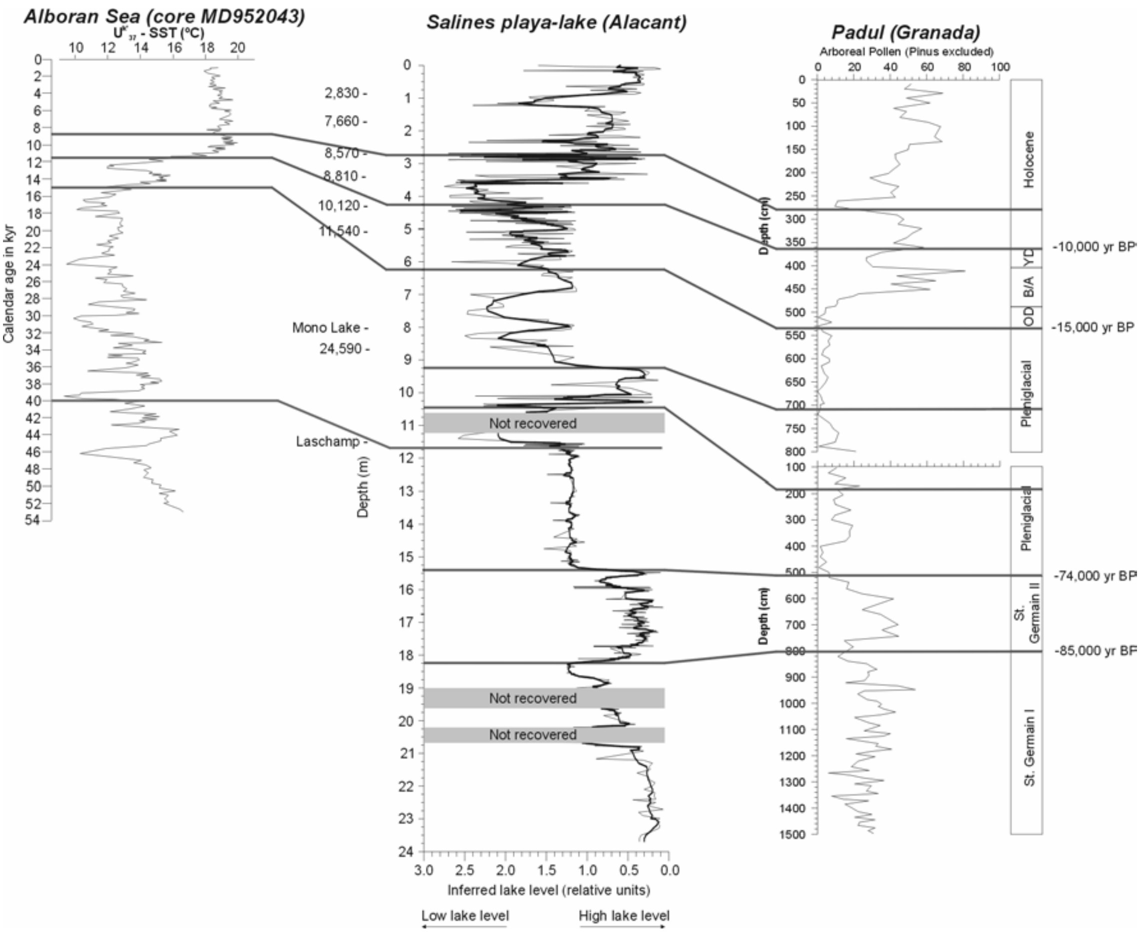

Fig. 3.1. *Reconstruction of the evolution of the Salines lake (Alicante) and its comparison with the pollen diagram of the sequence from the Padul bog in Granada (modified by Pons* and *Reille 1988) and with the reconstruction of the surface sea temperature (SST) carried out in palaeo-ecological survey MD952043 (Alborán Sea; modified from Cacho et al. 1999). The black lines show the visual correlation between the different sequences. The thick line on the Salines diagram shows the main evolution of the level of the lake (5 terms moving average). Source: Giralt* and *Juliá (2004).*

The climate on the Iberian Peninsula during the Holocene underwent noteworthy changes, particularly with regard to rainfall, which may have been related to latitudinal displacements and to changes in the intensity of the Azores anticyclone and of the polar front (Valero Garcés and Kelts 1997a). The spatial heterogeneity characterising the current ecosystems in Spain has existed for the last 10,000 years, as can be seen in the pollen data in lake sediments (Burjachs *et al*. 1997). In general, the lacustrine environments of Mediterranean influence have undergone oscillations with regard to water levels (Pons and Reille 1988; Giralt *et al*. 1999; Reed *et al*. 2001), probably related to seasonal water balance, which have been more notable than those of Atlantic influence (Peñalba *et al*. 1997; Allen *et al*. 1996; Sánchez Goñi and Hannon 1999; Luque and Juliá 2002).

The methodology used in the study of the reconstruction of climatic fluctuations during the Holocene, based on lacustrine sedimentary records, is now a multidisciplinary one (Bradley 1999; Last and Smol 2001). To date, most studies have considered the analysis of biological deposits independently from the stratigraphic and geochemical analysis, that is to say, that the lake’s past biology was not included within the geological framework (Cohen 2003). Our knowledge has been most advanced with the combination of Holocene studies of a biological nature (remains of Diatoms, Ostracods, Chironomids and pollen of higher plants; Battarbee *et* *al*. 2002; Reed 1998) with the geological ones (geochemistry, sedimentary facies, isotopic indicators, etc.; Valero Garcés and Kelts 1997b). In view of the study of the effects of climatic change on inland aquatic environments, the ideal solution would be to interrelate palaeo-studies of this nature with studies of the present-day aquatic ecology of the same ecosystem and its foreseeable future responses.

There are several studies of Holocene reconstruction in Spanish environments included in the Ramsar Convention. To our knowledge, studies have been published on Banyoles (Pérez i Obiol and Juliá 1994), Chiprana (Valero Garcés *et al*. 2000a-c), Gallocanta (Rodó *et al*. 2002), Tablas de Daimiel (Dorado *et al*. 2002) and Zóñar (Valero Garcés *et al*. 2004).

3.3.2. Effects on the number of ecosystems and their size

The number would obviously fall, if evapotranspiration increases in summer and rainfall does not, but we do not know to what extent [[see the Chapter Climate in Spain: past, present and climate scenarios for the XXI century; section 1.C.6]. Specifically, many temporary environments could disappear, although the forecasted increases in rainfall in spring and greater summer evapotranspiration could counteract this effect.

In general, it seems that there will be bigger variations in fluctuations in size. If we keep in mind that: 1) the size of aquatic ecosystems depends on their water balance and 2) certain conditions therein (rainfall, evaporation) will probably be altered by climatic change (Ayala-Carcedo and Iglesias 2000; CEDEX 1997; MIMAM 1998), many environments will probably be subjected to a reduction in size. This is especially true for semiarid environments, like most Spanish systems, for which a good relationship can be established between the aridity of the area and the size of the lake (Mason *et al*. 1994). This is why some lakes can change from deep to shallow, and from being thermally stratified to undergo frequent mixing. This effect will not occur in most of the mountain lakes situated in basins with a positive water balance; in these sites, the thermal stratification will be reinforced and will be prolonged in autumn, as has been seen in Lake Redó in the Pyrenees (Catalan *et al*. 2002). Furthermore, many environments will change from permanent to temporary, this applies to rivers and of lakes or wetlands. The reservoirs destined to uses other than simple regulation (irrigation, supply, etc.) could spend years at very low levels, practically dry.

The small karstic lakes could be affected to a certain extent by climatic change, due to their extreme dependence on the underlying aquifers and on the recharge/discharge dynamics. With regard to endorheic lakes, any possible effects on their size will depend on the local rainfall regime, which will continue to be geographically very variable.

In the fluvial environments, it is very difficult for the time being to discern the effects of a possible increase in sudden heavy discharge from autumn to spring. Changes in the seasonality of rainfall will lead to changes in flows and hydroperiods, which can be expected to have significant effects on the seasonality of the transport of materials and on the seasonality of animal and plant populations (Carpenter *et al*. 1992).

3.3.3. Effects on water quality

Results unpublished (Alvarez Cobelas, personal communication) indicate that there is no relationship between water quality and rainfall for the ten stream sites of the *Confederación Hidrográfica del Guadiana* (Guadiana Water Board) en el Alto Guadiana (period 1973-2002), which suggests that the possible effects of climatic change on water quality are uncertain for the time being. The quality of the waters may worsen after springtime, the effects of dilution being reduced due to increases in evapotranspiration and, secondarily, because perhaps there will be less contributions of water. Increases in torrential rainfall, associated to climatic change, could also affect the quality of the water on specific occasions (Murdoch *et al*. 2000). Excessive rainfall (above the inter-annual average) following prolonged droughts increases the concentrations of substances in some wetlands, like the Tablas de Daimiel National Park (Sánchez Carrillo and Álvarez Cobelas 2001).

Evidently, water quality is an applied aspect of climatic change that requires research, which has been non-existent up to now in Spain. Nutrient retention and self-purification are inversely related with streamflow under natural conditions (Butturini and Sabater 1998), but `polluted streams do not follow this relationship (Martí *et al*. 2004); there are, however, many aspects to be distinguished between flow, temperature, nutrient load and land uses in order to establish a parameterisation permitting applications and predictions.

3.3.4. Effects on biogeochemical cycles

It has been suggested that an increase in temperature and a decrease in rainfall will lead to diminished export of organic carbon and nitrogen from terrestrial ecosystems to river courses (Clair and Ehrman 1996). However, certain observations exist which indicate that an increase in rainfall over areas rich in accumulations of organic material in the watershed, like some of the ones in the Northeast of Spain, has generated an increase, at lest a transitory one, in the export of dissolved organic carbon and metals to the rivers (Freeman *et al*. 2001).

3.3.5. Effects on the biota

Although the summertime drought in many fluvial streams has favoured the existence of a flora and fauna adapted to this extreme situation, and therefore the existence of endemic species of macroinvertebrates, fish and riparian vegetation, it is likely that we are witnessing – at least transitorily – a clear drop in biodiversity, if the area of extreme environments increases [see the Chapters on Plant Biodiversity and Animal Biodiversity]. In the vegetation of riverbanks, an increase in tamarisks (*Tamarix*) is expected, compared with salicaceae (*Salix*) and poplars (*Populus*; Stromberg *et al*. 1996). The oleander (*Nerium oleander)* will probably spread. In many areas, the *tamujo* (*Flueggea tinctoria*), typical of cold, acidic temporary rivers, could replace the alder (*Alnus*). In the vegetation emerging from the wetlands, clearly amphibious species may be favoured over the genuinely aquatic ones (for instance, *Phragmites* and *Scirpus* may end up dominating in most of the wetlands over *Typha* or *Cladium*); whatever the case may be, it seems certain that the competitive interactions will be substantially modified (Alvarez Cobelas *et al*. 2001).

Mass proliferation of phytoplankton may occur in eutrophic and hypertrophic environments, like many reservoirs and lakes, in which a higher temperature could favour sudden and excessive growth (Carpenter *et al*. 1992; McKee *et al*. 2003).

In fluvial systems not subjected to dessication, the rise in temperature will generate more primary production in the riparian zone, which –together with a higher concentration of particulate and dissolved organic carbon of an allochthonous nature– may favour higher primary and bacterial production in lakes, rivers and wetlands (Bazzaz 1990; Schindler 2001). It must be remembered, however, that temperature has a greater effect on respiration than on photosynthesis, and it is therefore foreseeable that the biogeochemical processes related to the decomposition of materials will accelerate. In the same way, secondary production will increase, because temperature is a key factor in animal metabolism (Benke 1993). The tendency towards warming of the water mass seems to lead to the destabilisation of the composition of communities of river macroinvertebrates and to a decrease in their global diversity due to the effect of the dominance of very few species, which may lead to a decrease in their faunistic richness (Gutiérrez Teira 2003).

The rivers maintaining a subsurface flow during the summer period can accommodate specialised limnephylic Trichopterans, which will live during the dry period as larvae in diapause or as pupae. If the drought is more intense, many adapted species of aquatic insects will spend this time as an egg; this capacity is noteworthy in endemic cryophilic species of Plecopterans such as *Thyrrenoleuctra* and *Guadalgenus*. The species with a long life cycle (several years) may have adaptation problems in mid-mountain rivers, due to the fact that these could become temporary reaches. These problems will probably be more serious in the Central and Iberian Systems, whose geological substrate is impermeable, which means that their baseline discharge during the low water period (which is already low) will tend to disappear.

The larger river fish (barbel and Iberian nases) are capable of developing different types of migratory strategies in order to tolerate the pronounced low water level, either swimming upriver until they find permanent waters, or downriver to the convergence with the main rivers. The most peculiar endemic fish are small-sized (*Squalius alburnoides, Chondrostoma lemmingii*, *Iberocypris*) and their basic adaptation consists in waiting during the summer in isolated pools in conditions of overpopulation (Carmona *et al*. 1999). Their isolation has led to the adoption of parthenogenetic reproductive mechanisms, as in the case of the chub (*Squalius alburnoides*; Fernández Delgado and Herrera 1994) with triploid specimens. The habitat of the Salmonids will be reduced (Eaton and Scheller 1996).

This can already be seen in the salmon captured in the rivers of Northern Spain (Fig. 3.2); in the North Atlantic, these reductions in the salmon catches have been linked to temperature increases in the sea water, resulting from climatic change (Friedland *et al*. 2003) [see also Chapter on Animal Biodiversity]. The fauna of the mid-level reaches can progressively invade the upper reaches of the rivers if the water temperature increases, thus substituting strictly cold-water fauna of the more mountainous zones (Rahel *et al*. 1996). As a consequence, the autochthonous trout populations will become fractionated due to the reduction of their habitat, which would favour processes of genetic drift, and eventually, speciation. In this process, the actions related to the reintroduction and management of species of fish-farming interest may be determinant in the future of local populations.

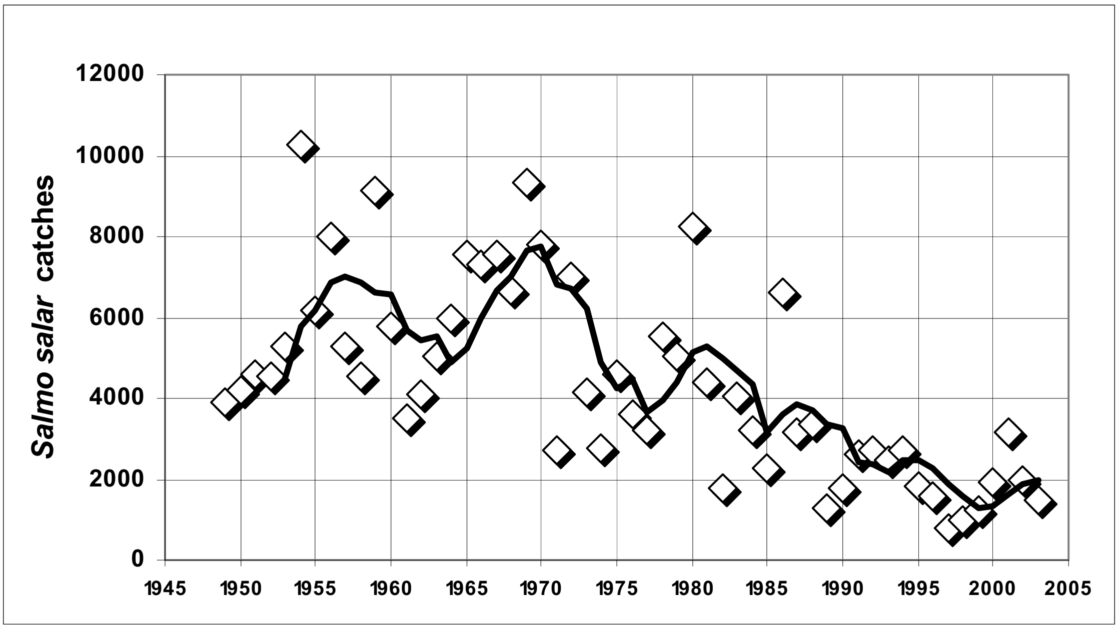

Fig. 3.2. *Long-term annual catches of salmons (Salmo salar) in northern Spanish rivers. The line is a five-terms moving average. Data source: Francisco Hervella, Galicia local government.*

In a general context, it is likely that the interactions between the benthic biota and the free-swimming ones will be modified (Lake *et al*. 2000).

3.3.6. Specific effects on the different types of ecosystems

3.3.6.1. Wetlands

Given their variety and intrinsic heterogeneity, the effects of climatic changes will depend on the particularities of each system, and it is therefore difficult to make a general evaluation. Given the irregular morphometry of many of them, the changes in volume will have unpredictable effects on their flooded area. However, there are certain predictable tendencies in some of the relevant processes in this type of environments; the specific behaviour of a determined wetland will depend on the local balance of these. Thus, temperature rises will increase the rate of microbial processes (Schindler 1997), the evaporation of the water surface and the transpiration of the emerging plants (Sánchez Carrillo *et al*. 2001). This increase in transpiration will probably generate more saline environments, synergistically favouring the dominance of species more tolerant to salinity (Lissner *et al*. 1999a) and to the lack of water, such as the reed (*Phragmites*), and lagged effects may also occur (Fig. 3.3). In the water balance, the anthropogenic changes in the uses of the water in the surroundings of the wetlands will also be very important. The decreased water supply involves a decrease in the hydroperiod which, in turn, will limit the recharge of the aquifer underlying the wetland (Sánchez Carrillo *et al*. 2005).

Changes in the types of vegetation will generate changes in the functions of the wetlands, particularly in the more complex ones (Doñana, for example, see Section 3.4.2), preferentially favouring one of the plant components of the landscape, and therefore, reducing diversity (Öquist *et al*. 1996).
In conditions of drought, erosion will be favoured. When there is abundant water, the rise in temperature will favour the faster decomposition of organic matter (Poff *et al*. 2002).

There will be changes in the amount and the timing of methane- and nitrous oxide emissions (Öquist *et al*. 1996). The permanent desiccation of many wetlands due to climatic change will obviously decrease the emissions of these greenhouse gasses.

Increases in CO_2 will increase the fertilisation and primary production of helophytic vegetation, but also the plant tolerance to stress (photoinhibition, drought, salinity; Lissner *et al*. 1999a-b).

The foreseeable droughts will promote fires, which may be very big ones in the case of wetlands with big accumulations of carbon (peat; de Bustamante *et al*. 1995).

Changes in the vegetation and in the flooded surface, depending on alterations in hydrology, will probably bring about modifications in the biogeochemical cycles and in the populations of vertebrates and invertebrates that depend on the vegetation (above all, insects and birds; Roshier *et al*. 2001).

3.3.6.2. Rivers

In general, the baseline discharge will decrease, which will lead to an increase in the number of temporary rivers and reaches of rivers with flows that are only seasonal. Furthermore, the warming will raise the water temperature, which can lead to the displacement upstream of the zoning of the biocenoses. In this sense, it is interesting to take into consideration that the effect of the increase in air temperature on the increase in water temperature is not independent from rainfall. In this relationship, rainfall has a negative, quadratic influence (Jones and Thompson

2003). Decreased rainfall would therefore favour an increase in river temperature, which may be relevant in trout zones.

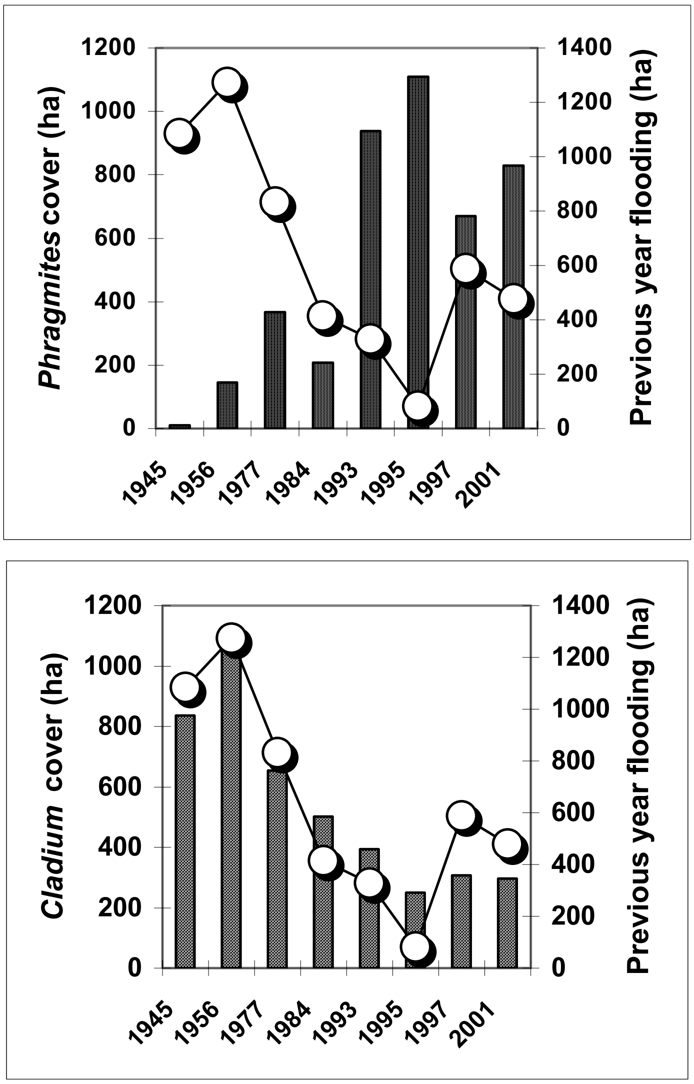

Fig. 3.3. *Annual cover (vertical bars, left-hand scale) of the two main species of vegetation emerging in Las Tablas de Daimiel National Park and flooding area in the previous year (open squares, right-hand scale) during the period 1945-2002. The representative covers are based on the aerial photography available for the period 1945-1997. Although it is not shown here, there is also a different relationship between flooding of the wetland in the preceding year and the cover of each species, which is a direct one in the case of cut-sedge (Cladium) and an inverse one in the case of the reed (Phragmites). In conditions of increasing aridity, resulting from climatic change, the spread of the reed would be favoured. Unpublished data by Cirujano* and *Alvarez Cobelas.*

A decrease in the flows would generate a drop in the concentration of dissolved oxygen, which is of particular importance if, besides, there is organic pollution and an increase in temperature (Jenkins *et al*. 1993).

Flooding, which causes an increase in suspended solids in the river channels, may be of greater importance in arid environments, where the soils are subjected to more erosion and the rainfall-runoff relationships are not linear (Arnell *et al*. 1996).

The increase in evapotranspiration in small watersheds will lead to a decrease in flows, and the effects will be more obvious in the reception reaches.

Changes in river hydrochemistry will be due to changes in the weathering of the rocky substrates of the watersheds in the zones with more humid, hotter climates (Ávila *et al*. 1996). Temperature increase will lead to a rise in the nitrification of the soils and, through runoff, increased nitrate in rivers (Jenkins *et al*. 1993). The same will occur with organic nitrogen in predominantly agricultural basins (Bernal *et al*. 2003). This effect will be more evident because of the intense flooding taking place after droughts.

In the rivers of the more arid areas (mainly in the Southwest of the Iberian Peninsula), ecological dynamics will be very susceptible to changes in the variability of the flows resulting from climatic change (Fisher *et al*. 1998), which can also affect seasonal rivers located in other parts of the Peninsula.

3.3.6.3. Lakes and reservoirs

Climatic change will have important effects on the ice-sheet in mountain lakes, as suggested by the simulation by Thompson *et al*. (2005), which shows that there are certain elevations that are more sensitive than others to these effects, and that they may undergo big changes in sensitivity (Fig. 3.4).

In the lakes with stable stratification (such as the Ruidera lagoons), the temperature of the epilimnion may increase by 1 to 4ºC with climatic change; however, if the stratification is greater, the hypolimnion will cool by several degrees. It seems clear that the stratification will last longer, and there will be a subsequent bigger consumption of oxygen in the deeper zones and the likelihood of anoxic conditions will increase. In the alpine lakes (above 1,500 m.a.s.l.), if the duration of the ice and snow cover is reduced, there will be less decreases in oxygen in the deeper layers and less liberation of phosphorus from the sediment. Springtime production will probably drop in favour of greater production in autumn.

In lakes the warming will increase primary production in the epilimnion if the stratification is more prolonged. The oxygen will also diminish in the deeper layers due to the increase in primary production and sedimentation, resulting from the increase in primary production, which will generate changes in the benthic fauna (Schindler 1997).

The drop in the level of the lake will affect the littoral area in those lakes that can vary their level significantly, this fringe is usually the most productive one and acts as a transition area between the terrestrial ecosystem and the aquatic one (Wetzel 1990). During the periods of ecological instability of the vegetation in the watershed, the overflowing of the smaller lakes located in deforested areas could accelerate with the reduction of the coastal buffer that limits the input of sediments of terrestrial origin.

The increased weathering of the rocks, resulting from simple thermal kinetics or from increases in the metabolism of the plant communities, due to increased air temperature, probably generates an increase in the alkalinity of the lakes.

With the thermal increase, the organic pollutants present in the water pass to the atmosphere more rapidly, and reach the higher altitudes more quickly, and these will become polluted more easily as a result of atmospheric deposition (Grimalt *et al*. 2001). The mobilisation of metals and metalloids (arsenic, lead) from the basin to the aquatic systems of cold areas will increase (Camarero *et al*. 2004), due to a greater mobilisation of these substances in the soils and to their atmospheric transport.

The possible effects of global warming on the trophic networks of the lakes are still to be debated (Jeppesen *et al*. 2003; Scheffer *et al*. 2003).

Lastly, we are still unaware of those factors which will affect the future redistribution of the lacustrine fauna because, in most cases, we know nothing of their dispersion in the past.

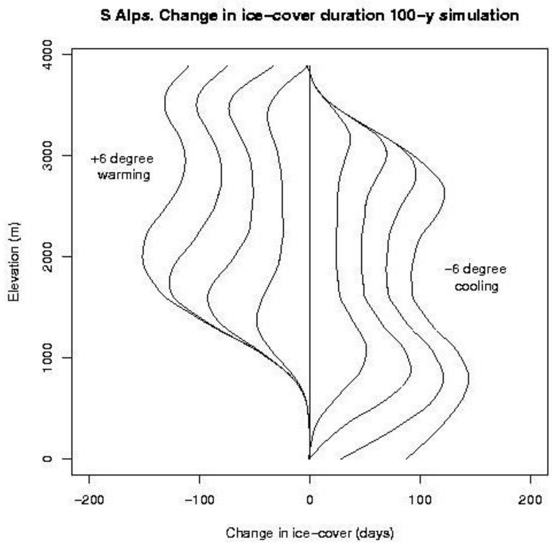

Fig. 3.4. *Simulation of the changes in the duration of the ice-cover of the lakes existing to the South of the Alps, between 0 and 4000 metres altitude. Nine different scenarios of climatic change were tested, using a simulation of one hundred years (cycles of one and a half years plus atmospheric time). Source: Thompson et al. (2005).*

In general, for the reservoirs we could apply the same assertions as for the lakes, but taking into account their higher water renewal rate, the extreme dependence of this rate on the water use of the reservoirs, and that they are usually subjected to greater eutrophication (Alvarez Cobelas *et al*. 1992), it would be very risky to make any type of prediction (Toja, personal communication).

3.4. MORE VULNERABLE AREAS

In accordance with the results presented in the Chapters Climate in Spain: past, present and climate scenarios for the XXI century and Hydrological Resources, the following areas will probably be the most vulnerable ones:

Endorheic environments

Many of these ecosystems are located in areas in which average rainfall will decrease and where its seasonal distribution will be very altered (La Mancha wetlands, for instance); these areas are therefore threatened with extinction.

High mountain lakes and ponds (1600-2100 m altitude) in the areas with deciduous forests and in those bordering on the forest.

High mountain rivers and streams (1800-2500 m altitude)

These ecosystems contain cryophilic endemic insects, whose distribution is already restricted. The dimension of their habitats will probably be reduced, as a result of climatic change, to a size that is critical for their survival.

Coastal wetlands

The coast will slowly reorganise itself in a natural manner if there are changes in sea level. However, given that there are numerous civil works on our coasts, perhaps there will be additional complications of the administrative kind which may limit this reorganisation.

Environments depending on groundwaters

The drop in groundwater levels, probably due to consumptive uses and to the decrease in recharge because of climatic change, will affect those environments considerably.

In the spatial sense, and taking into account the projections of the climate models (Section 1.3.6 of the Chapter on Climate in Spain: past, present and climate scenarios for the XXI century), it seems likely that there will be an increase in the rainfall in the NW of the Peninsula and a decrease in the southern zone and in the Mediterranean in wintertime, which is the most important time of year for the water recharge of the aquatic ecosystems.

3.4.1. Specific cases

Table 3.1 shows the information obtained on the incidence of the possible effects of climatic change on certain morphometric and biogeochemical aspects of determined inland aquatic environments in Spain, and was provided by the experts who have been working with these ecosystems for a long time. The information is still at the early stages and must be considered with care, as we still lack specific studies on these possible changes in all the ecosystems considered. There is a particular lack of direct information related to climatic change for most of the environments included in the Spanish list of Ramsar wetlands. A small section dedicated to Doñana is also provided, this being the most internationally known wetland of the Iberian Peninsula.

Table 3.1. *Likely effects on the most studied Spanish inland aquatic ecosystems, related to climatic change, based on the experience of the authors contributing to this chapter. These effects are characterised as non-existent (0), rare (1), considerable (2), important (3) or very important (4). The asterisk indicates environments included in the International Ramsar Convention for the Conservation of Wetlands.*

Name	Geographic location (central point)	Changes in permanence (temporary *vs* permanent)	Changes in size	Changes in the biogeochemical cycles	Changes in the biota
Doñana National and Natural Parks (Sevilla-Huelva) (*)	36º 34' N 6º 24' W	3	3	2	4

Tablas de Daimiel National Park (Ciudad Real) (*)	39º 08' N 3º 43' W	4	4	2	4
Albuferas de Adra (Almería) (*)	36º 45' N 2º 47' W	2	4	3	4
Main lake of the Albufera de Valencia (Valencia) (*)	39º 20' N 0º 20' W	0	1	4	4
Dune ponds of the Albufera nature Park in Valencia	39º 20' N 0º 20' W	4	3	3	2
Lakes of Alcázar de San Juan (Yeguas and Camino de Villafranca) (Ciudad Real) (*)	39º 24' N 3º 15' W	3	2	2	4
Arcas Lakes (Cuenca)	39º 59' N 2º 7' W	3	3	1	2
Banyoles Lake (Girona) (*)	42º 7' N 2º 45' E	0	0	2	2
Lakes of Cañada del Hoyo (Cuenca)	39º 59' N 1º 52' W	2	2	3	2
Lagoons of the Ebro Delta (Tarragona) (*)	40º 39' N 2º 32' E	2	2	2	2
Fuente de Piedra Lake (Málaga) (*)	37º 06' N 4º 46' W	1	0	1	1
El Hito Lake (Cuenca) (*)	39º 52' N 2º 41' W	3	2	2	4
Gallocanta Lake (Zaragoza-Teruel) (*)	40º 50' N 2º 11' W	4	4	4	4
Manjavacas Lake(Cuenca) (*)	39º 25' N 2º 50' W	3	2	2	4
La Nava Lake (Palencia) (*)	42º 04'N 4º 44' W	3	2	2	4
El Prado Lake (Ciudad Real) (*)	38º 55' N 3º 49' W	3	2	2	4
Puebla de Beleña ponds (Guadalajara) (*)	40º 53' N 3º 15' W	3	2	2	4

Redó Lake (Lleida)	42º 38' N 0º 46' E	0	0	2	2
Ruidera Lakes (Ciudad Real/Albacete)	38º 56' N 2º 37' W	3	3	2	4
Sanabria Lake (Zamora)	42º 07' N 6º 43' W	0	1	2	2
Sierra Nevada Lakes (Granada)	37º 05' N 3º 05' W	0	4	4	4
De la Vega Lake Ciudad Real) (*)	39º 49' N 2º 56' W	3	2	2	4
Villafáfila wetland (Zamora) (*)	41º 49' N 5º 36' W	0	0	0	1
Aiguamolls de l'Empordá (Girona)	42º 13' N 3º 6' E	1	1	0	0
Salburúa Wetland (Alava) (*)	42º 51' N 2º 39' W	3	2	2	4
Platja d'Espolla (Girona)	42º 9' N 2º 46' E	0	0	1	1
River Agüera (Vizcaya-Santander)	43º 18' N 3º 16' W	0	2	2	2
Chicamo River (Murcia)	38º 12' N 1º 03' W	3	4	3	3
Riera de Fuirosos (Barcelona)	41º 42' N 2º 34' E	1	0	2	1
Mouth of the River Guadalhorce (Málaga)	36º 40' N 4º 27' W	0	0	1	1
Riverine wells in the rivers Asón and Saja (Santander)	43º 10' N 4º 17' W	0	1	1	1
Riverine wells in the Parc Natural de la Albufera in Valencia	39º 20' N 0º 20' W	0	0	3	2
Aracena Reservoir (Huelva)	37º 55' N 6º 28' W	0	0	4	4
Arrocampo Reservoir (Cáceres)	39º 49' N 5º 43' W	0	0	0	0
Reservoir of El Hondo (Alicante) (*)	38º 10' N 0º 42' W	3	2	2	4

La Minilla Reservoir (Sevilla)	37º 43' N 6º 10' W	0	0	4	4
Sau Reservoir (Girona)	41º 58' N 2º 25' E	0	3	2	4
Torrejón Reservoir (Cáceres)	39º 47' N 5º 45' W	0	0	1	0
Arms of Ullibarri reservoir (Alava) (*)	42º 54' N 2º 32' W	3	2	2	4
Valdecañas Reservoir (Cáceres)	39º 49' N 5º 28' W	0	0	1	0

3.4.2. Doñana and climatic change

Its main aquatic systems comprise a marsh (of a seasonal nature and with variable salinity, supplied by rainwater and by surface runoff and with an area of around 40,000 ha), as well as a complex of coastal lakes located on the coastal aeolean area (supplied by phreatic water with low, very clean mineralisation covering 44,000 ha, including the National and Nature Parks). Furthermore, between the coast and the Arroyo de la Rocina stream, some peaty lagoons persist on siliceous sands, ranging from the Doñana Nature Park to the NW zone of Doñana National Park. These constitute the most vulnerable aquatic environment of Doñana. The area taken up by these ombrotrophic bogs has been considerably reduced since the beginning of the XVIII century (Sousa 2004), although this reduction has been particularly intense since the beginning of the XIX century (Sousa and García Murillo 2002, 2003).

Will the aquatic environments of Doñana undergo changes in their permanence? Yes. In the coastal lakes of the coastal aeolian area of Huelva, the volume of surface deposits and the piezometric levels will probably fall; the flooded surface will therefore probably decrease, although this is not yet very predictable, as it depends on the changes in the seasonality of the rainfall (Toja, personal communication). The water-rich peat heaths where *Erica ciliaris* dominates, currently a valuable relic (see Allier *et al*. 1974; Rivas Martínez 1979; and Rivas Martínez *et al*.; 1980; Cobo *et al*. 2002) will disappear and will be substituted by heaths of *Erica scoparia*, of lesser value for conservation. This will most probably affect the peat environments of Abalario and of Doñana National Park, which house much of Doñana's unique flora, such as carnivorous plants and sphagnum (García Murillo *et al*. 1995; García Murillo 2000, 2003). Therein there will also be an increase in eutrophication. With regard to the marsh, this change in conditions will result in an increase in helophytes and pastures, to the detriment of the submerged macrophytes, this, in turn, will increase the sediment accrual processes, which will create a positive feedback; in short, the sediment accrual speed of the marsh will accelerate.

Will the size of the aquatic ecosystems undergo changes? As we have said before, there will be changes, but these will depend on the successional stage of each environment in question. In general, the most plausible tendency will be towards the simplification of the natural habitats and of the biodiversity of the marsh and of the inland lagoons.

Will the climatic change affect its biogeochemical cycles? Probably. These changes will be particularly evident in the water-rich peat environments, characterised by a low concentration of nutrients and the accumulation of organic matter. The organic matter will cease to accumulate and the concentration of dissolved nutrients will increase, giving way to opportunistic species. In the marsh, as the submerged macrophytes diminish or disappear in a notable manner, the biogeochemical fluxes will follow other routes, as the different elements will fundamentally circulate through the helophytes and the pastures (Espinar *et al*. 2002).

Will the biota be affected by climatic change? There will be a decrease in biodiversity as a result of the decreased heterogeneity of the habitat. Likewise, there will be more change of invasion by exotic species (as is happening with the fern *Azolla*; García Murillo 2003).

Will the rise in sea level affect Doñana? Yes. Mush of the marshland is practically at sea level and is only separated from the sea by small dune walls, less than a metre high. If the sea level continues to rise at the present rates, a large part of Doñana will probably be taken over by the sea within a century.

Will there be marine intrusion? Currently, this does not exist (Lozano *et al*. 2002), but future changes cannot be ruled out if there are conflicts over the use of groundwaters in an area of intensive greenhouse agriculture and vast coastal tourist resorts.

3.5. MAIN ADAPTATION OPTIONS

The adaptations should be applied with regard to both the supply and the demand for water. In the first case, we must attempt to ensure the amount of water available for the aquatic ecosystems through water-saving policies, in the second case, by trying to reorient human demand towards low-consumption uses.

At the regional or local scale, there are no signs of any human adaptations aimed at mitigating or preventing serious effects (emissions of gases, carbon sequestration, etc.). At local scale, there may be some attempts to control flooding, improve biodiversity and reduce pollution (Arnell *et al*. 1996), both in lakes (Annadoter *et al*. 1999) and in wetlands (Zedler 2000; Angeler *et al*. 2003). In any case, it seems wise to point out that in a system of flows that has undergone as much intervention as in Spain, the water allocations to wetlands should be clearly defined in the watershed management, as recommended by the Ramsar Convention (ramsar.org/key_res viii_01_s.doc).

Having established that the adaptation of the inland aquatic ecosystems to climatic change is limited (Poff *et al*. 2002), we believe that the following measures should be taken:

3.5.1. Promotion of water-saving in agriculture

A generalised water-saving policy is urgently needed, and the technology already exists for increasing the efficiency of the irrigation systems. In this sense, we should consider a National Irrigation Plan that takes climatic change into consideration. Furthermore, the private management of the agricultural areas could be enhanced through agro-environmental measures in the vicinity of the aquatic ecosystems.

3.5.2. Promotion of aquifer recharge

This should be done in close consonance with the previous measure, and an attempt ought to be made to ensure that the recharge exceeds the discharge. The initiation of Specific Watershed Management Plans, within the National Hydrological Plan, should be used in this sense. An example of this would be the development of a Special Plan for the Upper Guadiana Basin to ensure the hydrological recovery and sustainability both of its aquifers and of the aquatic environments depending on them.

3.5.3. Promotion of recycling of waste waters

This needs to be further developed, and many important water uses (irrigation, for instance) do not require extreme cleansing. Much more attention must be paid to this point than has been done up to the present; the creation of artificial wetlands could be contemplated.

3.5.4. Improvement in the quality of surface waters

The discharge of pollutants must be reduced, and an attempt must be made to prevent clean or pristine ecosystems from being affected by pollutants in the future. The National Wastewater Treatment Plan and the transfer and application of the European Framework Directive on Water to Spanish law ought to facilitate this improvement, although the widespread problem of diffuse pollution has not yet been dealt with in Spain (Thornton *et al*. 1998).

3.5.5. Recovery of the floodable space within the River Channel Public Domain

Most rivers are very constrained by agricultural and housing development activities, but if the streams flow through public domain, they should be restored in cases of severe deterioration. This would favour the natural development of the riparian environments with the advantage of stimulating the development of this buffer zone to protect the inland aquatic environments from terrestrial effects.

3.5.6. Mass revegetation (forest or shrub) in watersheds, favouring the occupation of the space by autochthonous plants

Revegetation should be favoured to restore the riparian forest along those river banks where it has been eliminated or has become very deteriorated, whereby the natural function of each territory should be conserved.

3.5.7. Use of water transfers to provide minimum amounts to guarantee the survival of the inland aquatic ecosystems (ecological flows, minimum flooding levels, etc.)

This measure need only to be applied to areas of special interest for Nature Conservation (for example, environments included in the Ramsar Convention, habitats included in the Red Natura 2000, etc.) and only in exceptional cases, but always considering the needs of aquatic environments in national hydrological planning.

3.5.8. Promotion of the conservation of natural species and of the environmental connection between them within the framework of a restoration programme at national level

Special attention must be paid to the hydrological connection between ecosystems within the same watershed in order to promote the dispersion of endangered species.

3.5.9. Favouring accretion in coastal wetlands

Accretion should increase at a faster rate than the rise of the sea level, and transport of sediment by rivers in the case of deltas should be favoured. A clear case of anthropogenic interaction with the effects of climatic change is the Ebro Delta. Over the last 50 years, the construction of reservoirs on the middle- and lower reaches of the river has reduced the transport of sediments to the delta, thus reducing its size (Ibáñez *et al*. 1996); the forecasts for in sea level rises in certain parts of Spain (Section 3.2.3) indicate an exacerbation of this tendency in the near future.

3.6. REPERCUSSIONS IN OTHER SECTORS OR AREAS

3.6.1. Environmental conservation

If we do not mitigate the effects of climatic change, many ecosystems will disappear and we may have to invest more money in the conservation of the most appreciated ones. At the very least, it seems urgent to ensure the permanence of refuges and to prevent the fragmentation of habitats, in order to promote the persistence of certain species. In some cases there may be a need for active policies to generate new sites for habitats.

3.6.2. Tourism

The repercussions for tourism can be very serious, with more intense adaptation problems for hostelry and tourism businesses than for the tourists (Wall 1998). In the case of the Tablas de Daimiel marshlands, for example, there are around 200,000 visitors a year; in the years 1994-1995, at the height of the drought during that decade, the number of visitors was less than 10,000. Effects of this type can also be expected in other wetlands with a high influx of visitors, such as the Ebro Delta, Doñana and the Aiguamolls de l'Empordá.

Some effects of an occasional nature can also be particularly harmful for certain aquatic ecosystems. For instance, the *Romería del Rocío* fair, which usually attracts one million people every year, may end up affecting Doñana's water supply if the water resources used to supply these visitors diminish, which is likely in a context of climatic change (García Murillo and Sousa, personal communication).

3.6.3. Public protection (prevention of flooding)

As most of the fluvial streams of the Iberian Peninsula have been channelled, there will be less natural reduction of the effects of floods, probably more frequent with climatic change. We can also expect synergic effects: with an increase in flooding, malfunctions in the fluvial network (biogeochemical changes, effects on flora and fauna, etc.) will become more obvious.

3.6.4. Water supply

This is important in the case of water supply reservoirs and of aquifers used for supply (around one third of the population uses water from wells in Spain; Custodio *et al*. 1998). Dammed water with a higher number of "blooms" of algae –which will be favoured by climatic change (see Section 3.3.7)– will have higher purification costs.

3.6.5. Inland fisheries

As we have already seen, the habitat of the salmonids will be reduced. It is not clear what will happen to the autochthonous cyprinid fishes (barbel, Iberian naces). They may be replaced by more thermophilic and, in general, alien ones ("black-bass", wels, etc.).

3.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

3.7.1. Lack of series of reliable long-term data for the study of the effects of climatic change

Apart from tendencies, the short, medium and long-term scales of variability should be identified, taking into consideration the close dependence of the changes in aquatic ecosystems on those that occur in the terrestrial environments of the watersheds. There is a lack of long-term observation and follow-up of the natural processes associated with inland aquatic ecosystems. The existing series of long-term data were not designed for this; the water quality records, for instance, deal more with the effects of pollution by urban waste waters. A series of environments ought to be chosen for long-term monitoring in order to establish the effects of climatic change, ruling out those sites subjected to pollution and flow regulation. The lack of coincidence between the flow gauging stations and those engaged in sample collection in many of our control networks limits our capacity to evaluate the relationship between quantity and quality, with regard to certain details related to climatic change.

3.7.2. Still very little information on the ecological and biological state of the most important species

Many valuable environments have hardly been studied at scientific level, but from the point of view of the avifauna. As can be seen in Table 3.1, most of the Spanish Ramsar wetlands have not been studied from the point of view of aquatic ecology; we only avail of data, sometimes very preliminary ones, on 17 of the 49 national ecosystems included on the list.

The biological sampling has not been standardised. However, in order to implement the European Framework Directive on Water in Spain, attempts are being made to fill this gap, with methodologies for biological study, levels of reference of aquatic environments and periodical reviews related to possible changes (among these, climatic ones) that might modify these reference conditions.

3.7.3. Lack of knowledge of hysteresis effects

No ecosystem, and in particular, the aquatic ones dealt with here, ever presents the same response to one same disturbance. There is always a certain degree of hysteresis in their behaviour which is difficult to assess, but the bigger the system, and the more closed the exchange of materials and species, the bigger the hysteresis effect will probably be. In this sense, lacustrine systems and wetlands may present a greater component of hysteresis (Comín *et al*. 1992). There are very few studies in this respect and, as an example, it is worth stating that in alpine lakes the production dynamics and populations of Chironomids seem to follow an adjustment to the climate at scales of tens of years (Catalan *et al*. 2002). Thus, it is likely that the incipient effects of the climatic change that is already occurring will manifest themselves in the next decade.

3.7.4. Lack of knowledge of the effects of abrupt or gradual changes in terrestrial plant communities and in the geology of drainage basins on aquatic ecosystems

Because drainage basins have so much influence on our aquatic ecosystems (Section 3.2), we have to consider the effects of climatic change on drainage basins. We are, however, still uncertain about the direction and magnitude of these basin effects.

3.8. DETECTING CHANGE

This is closely related to the previous section.

3.8.1. Long-term studies for the observation and follow-up of changes

Apart from tendencies, we should also identify short, medium and long-term scales of variability, taking into consideration the close dependence of the changes in aquatic ecosystems on those that occur in the terrestrial environments of the watersheds.

3.8.2. Use of models of inland aquatic ecosystems

In our case, and given the aforementioned dependence on the watersheds, the usefulness of the models will depend on the reliability of models for the terrestrial environment of the watershed. The better the basin models are, the better those of the aquatic environments will be.

No empirical models on the distribution of species in inland aquatic environments exist that explain species distribution on the basis of a limited number of environmental variables, among which could be those associated with climatic change (water temperature, flow, hydroperiod, etc.)

3.9. IMPLICATIONS FOR POLICIES

3.9.1. Scientific policy

The Ministry of Education and Science should promote research into the effects of climatic change on inland aquatic ecosystems and of the mitigation of these effects by means of ecological restoration. Most of the projects approved to date merely contemplate changes in the past. Hardly any projects have been approved dealing with the monitoring or detection of the effects of current climatic change. The Public Works and Agriculture Ministries should also become involved.

3.9.2. Inland fisheries policy

The Regional Governments (depts. of Agriculture and Fisheries or Environment) must be involved in fisheries policy. Given the foreseen changes in fauna (Section 3.3.5), the regulation and management of the fish populations must be adapted to the changes we can anticipate.

3.9.3. Environmental policy

This is the Responsibility of the Ministry of the Environment and of the Regional Autonomies (depts. of the Environment and Public Works), and they should become involved in the conservation of protected natural areas, many of which include inland aquatic ecosystems. This policy should be applied at the level of watersheds, including subterranean waters, if they are to be effective.

3.9.4. Regional and local tourism policy

To be implemented by the Regional Governments (Tourism Departments) and the Town Councils (Tourism departments) located in the vicinity of protected natural spaces.

3.10. MAIN RESEARCH NEEDS

3.10.1. Long-term studies of the environmental effects of climatic change in Spanish inland aquatic ecosystems in sensitive areas

Implementation of a series of long-term studies in standard ecosystems, located in uncontaminated and unregulated watersheds, such as the Pyrenean lakes (*e.g.* Lake Redó), Lake Sanabria, Sierra Nevada lakes, river environments of the Upper Duero and the Upper Tajo, ponds on *rañas* in northern Palencia, Ramsar wetlands, etc.

3.10.2. Studies of water quality in relation to climatic change

To date non-existent.

3.10.3. Design of a system of biological indicators of the impacts of climatic change

In collaboration with the work groups transferring and applying the European Framework Directive on Water for Spain, one ought to be designed for algae, macrophytes and aquatic macroinvertebrates.

3.10.4. Implementation of the existing models for the detection of effects of climatic change on inland aquatic ecosystems in Spain

To date non-existent.

3.10.5. Urgent finalisation of the inventory of the flora and fauna associated with aquatic environments, particularly of non-vascular plants and invertebrates, together with a description of their distribution on the Iberian Peninsula, Balearic Islands and Canary Islands

Many of these have not been started, but they are fundamental in order to know what exists at the present time and what might appear or disappear due to the effects of climatic change.

3.10.6. Study of the dispersion and ecology of invasive plants and animals (*Azolla caroliniana*, *Eirocheir sinensis*, *Dreissena polymorpha*, *Micropterus salmoides, Esox lucius*, etc.) in relation to climatic change

Invasion by certain species from other parts of the planet is to be expected to increase. Yet, little is known on the ecology involved in invasions of aquatic species on the Iberian Peninsula, apart from the mere detection of these processes.

3.10.7. Study of impacts and adaptations to climatic change at genetic, eco-physical, population and ecological levels

Crucial, given the existing lack of knowledge on the subject.

3.10.8. Studies of the changes in the biodiversity of macrophytes and vertebrates at local level associated with climatic change

To be carried out at the Ramsar sites; these are relatively simple evaluations, but must be done periodically over decades in order to assess what changes have occurred in biodiversity and how these changes can affect the functioning of the ecosystems.

3.10.9. Simulations *in situ* of the possible changes in determined ecosystems (small lakes, wetlands and watersheds), altering environmental conditions in an analogous way to the predicted changes

These simulations could be used to appreciate in a realistic manner changes in the ecosystems before they occur, and could generate very valuable information for the application of adaptation measures.

3.10.10. Study and inventory of biological communities georeferenced at regional scale

To be carried out primarily in the plant communities, this study aims at establishing their present environmental state in order to identify future transformations therein due to climatic change.

3.10.11. Study of the effects of the mitigation measures

Vital for evaluating their efficiency and necessary changes.

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4. IMPACTS ON MARINE ECOSYSTEMS AND THE FISHERIES SECTOR

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ABSTRACT

The climatic system is defined by the interaction between atmosphere and ocean, and climate change cannot be accounted for if we do not consider the role played by the ocean. In turn, the ocean is altered by changes in wind, temperature and rainfall regimes and continental inputs and evaporation. Temperature increases have been detected on all Spanish coasts, as well as changes in the seasonality and intensity of certain oceanic processes, such as upwellings. There is evidence that the change in oceanic climate has been accelerating over the last few years. Climate change will also affect the exchange of greenhouse gasses between the atmosphere and the ocean, reducing the solubility of carbon dioxide.

Spain presents a great variety of ecosystems and marine species, which provide resources (fish and shellfish fisheries, recreation, marine farming), goods and services. Ecosystems are affected by changes in the hydrographic and environmental conditions deriving from climate change, as occurs with terrestrial ecosystems. The change is generating multiple direct and indirect responses; some of these interact with other human uses (fisheries, developments on coastline, etc.) and generate uncertainty with regard to each of the factors at play. The effects will differ for upwelling ecosystems or those comprising stratified areas, and for coastal and oceanic areas. Reduced productivity is predicted in Spanish waters, due to their characteristics as subtropical or warm temperate seas.

Changes have been detected in species distribution, with an increase in species from temperate and subtropical waters. Likewise, there has been a decrease in the abundance of boreal/northern species. Changes have been detected in many groups of organisms, from phytoplankton and zooplankton to fish and algae. It is very likely that there will be modifications in the future abundance and distribution of many species. An increase has been detected in invasive species, but the role played by climate change in this respect has not been studied.

Changes in ecosystems and in marine trophic networks are affecting resource species, especially during the larval phase and recruitment. Certain species are fished less and others more. We are unaware of the future balance between profits and losses caused by these changes, which cannot be isolated from the changes caused by the exploitation of fish species.

Marine culture that is not provided with food supplements might be affected by reduced marine productivity. Increases have been noted in the abundance of species of toxic phytoplankton or of parasitosis in cultured species. The evidence appears to indicate increased losses in cultures associated with the presence of these species, favoured by temperature increases in coastal waters.

The areas and systems most vulnerable to climate change involve benthic communities, comprising organisms attached to substrate, or associated species. Among the most affected are seagrass meadows.

The management of coastal marine ecosystems and of marine species should be considered from multispecific ecosystem point of view. The search for solutions should be promoted in order to mitigate the effects of direct human activity, and to conduct medium and long-term follow-up of interventions.

Among the research needs, we can highlight the consolidation of long-term environmental and ecological follow-up networks, along with the use and improvement of existing ones. Accessible databases should be promoted. Spanish participation in international programmes should also be promoted, as well as research plans aimed at learning of the impacts of oceanic change on species and ecosystems, from both a retroactive and prospective point view.

4.1. INTRODUCTION

4.1.1. Brief description of the area and characteristics of the oceanic waters of Spanish coasts

The Spanish coastline, including the archipelagos, measures around 7,880 km, which is quite an appreciable figure. It is washed by the Atlantic and the Mediterranean, an ocean and sea, respectively, of very different characteristics. The continental margin are generally narrow, as the coastal waters are. There is a great diversity of environments, from Boreal-Atlantic conditions on the coast of Galicia, to subtropical ones of the coasts of the Canary Isles. On all Spanish coasts, a summer period of stratification has been detected, the duration of which is variable. Much of Spain's Atlantic coast is affected by upwellings, annual or seasonal, and by the circulation of the Subtropical Gyre and the eastern limit of this. This circulation is modulated on Spanish coasts by currents the direction of which varies according to the season of the year; there is a noteworthy current associated with the continental slope in the West and North of the Peninsula running in a northerly direction in autumn and winter. The Mediterranean coasts are affected by slope currents (cold for much of the year) and by a prolonged period of stratification. The different processes (physical, chemical and biological) taking place in the exchange thereof between the Atlantic and the Mediterranean and their influence on the hydrological characteristics of the ocean, have made Gibraltar a paradigm as far as Straits are concerned. In the south of the Peninsula, upwelling processes are associated with these exchanges.

4.1.2. State of the resources exploited. Importance in the national GDP

The participation of the fisheries sector in Spain's economic activities is very similar to EU average, at around 1% of the GDP. It is of greater importance in the Northwest and North of Spain, without forgetting other regions, in particular Andalucia and the Canary Isles.

The economy of certain regions depends to a great extent upon fisheries (which represents 10% of the GDP in the Galicia regional autonomy), which is of great strategic value for these regions. Around the primary fisheries sector, a series of related complementary activities has been generated, with a multiplying effect (marketing, transformation, shipbuilding, technology transfer, auxiliary industry and services), and these comprise an inseparable economic and social unit. In the areas where it exists, the fisheries sector constitutes a traditional activity, from which a valuable source of food resources is derived, makes technology transfer possible and promoting a geographic concentration of intersectorial relationships and activities. Fisheries and marine farming are considered to be very important for many coastal areas, because employment is associated with the capture and transformation of this resource, regardless of the amount captures or the efficiency of the processes, especially in the case of artisanal fishing.

The Spanish fisheries sector comprises a series of fleets working in national fishing grounds in the Atlantic and the Mediterranean, in mid-distance fisheries (for example, waters of Scotland and Ireland, Celtic Sea, Bay of Biscay, Northwest Africa) and more distant zones (Newfoundland, Malvinas, Gulf of Guinea, etc.). The artisanal fleets fishing close to the coast.

Total Spanish production of marine fisheries resources showed a sustained downward trend from 1970 (1.4 million t) to 2002 (1.1 million t) according to statistical data by the FAO (Figure 4.1.A). Spain's fisheries in the Mediterranean is stabilised above 100,000 t. The production of big oceanic pelagic species (tuna and swordfish) presented a sharp rise from 1970 to 1990, and has remained relatively stable since then (Figure 4.1.B).

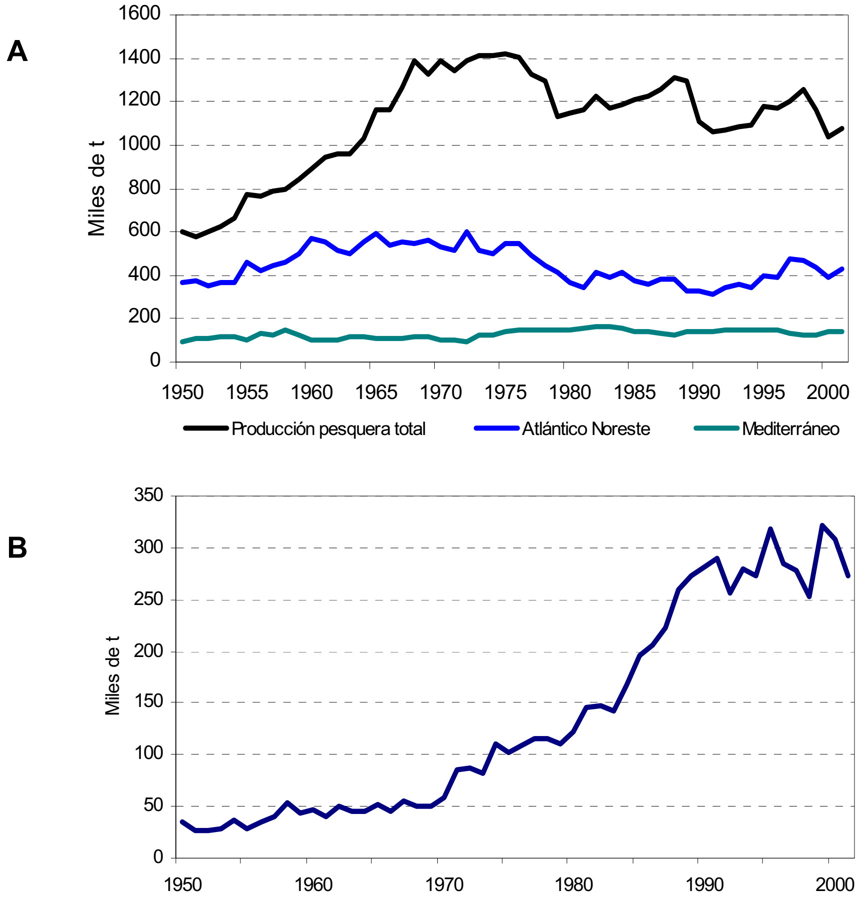

Fig. 4.1. *A: Marine fisheries production (fish, molluscs, crustaceans) (thousand of t) in Spain: total in the Northeast Atlantic and the Mediterranean, 1950-2001. B: Total Spanish catches of pelagic ocean species (tuna and swordfish), 1950-2001. (Source: FAO statistics).*

Approximately one third of Spain's fisheries production comes from the Northeast Atlantic, and the current contribution of groups of pelagic species and demersal species is very similar.

The fishing grounds of the Iberian area of the Atlantic are being intensely exploited and Spanish catches of the main pelagic and demersal species show a general downward trend which is more evident in demersal species (hake, angler fish, dory and Norway lobster), but other catches are increasing, such as mackerel, although these do not reach the same quantities.

Apart from fish, other marine products are taken from the Northeast Atlantic, such as algae, crustaceans and molluscs. The evolution of these catches has presented a downward tendency since the 70s, according to statistical data by the FAO (Figure 4.2). There appears to have been a sight increase in recent years in the production of algae and molluscs, although these statistics may not be reliable.

Spain's marine aquaculture production (Figure 4.2) was 320,000 t in 2003. Much of this production (approximately three quarters) corresponds to mussel culture in the *rías* of Galicia (Labarta 2000). The production of farmed sea fish (gilthead, sea bass, turbot, tuna) represents 6%, with a big increase in recent years, and production of other molluscs (clams, cockles, etc.) 4%, this figure having remained the same in recent years (Labarta 2000).

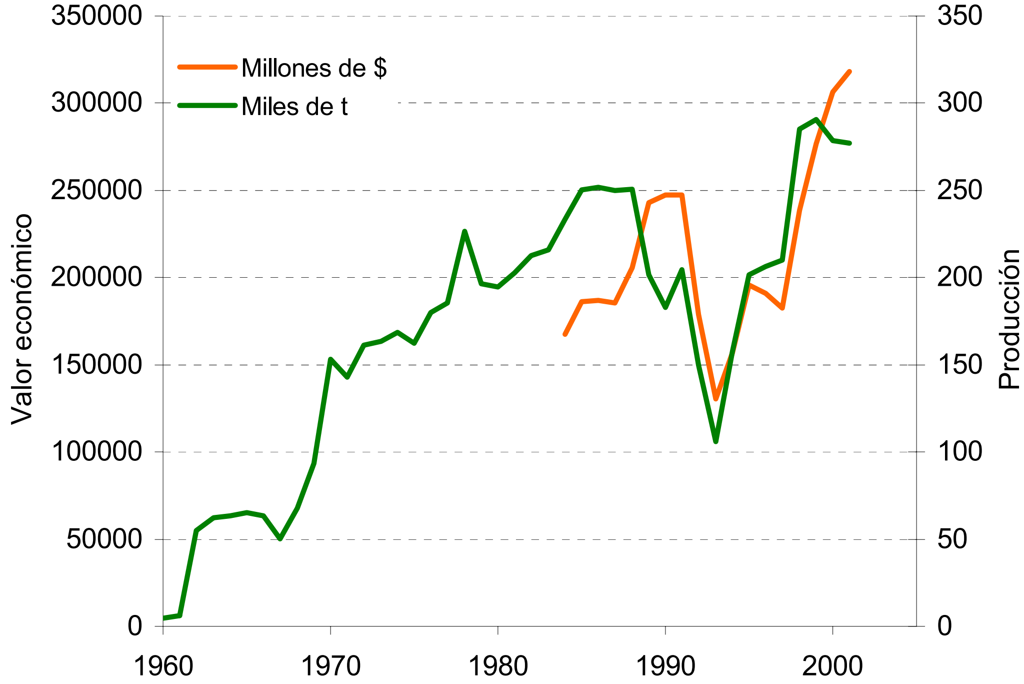

Fig. 4.2. *Spanish production of marine aquaculture and economic value. (source: FA statistics) and JACUMAR)*

Another series of activities, of which the main exponent is coastal tourism, in which sports fishing, diving and sailing should be included, constitutes an important set of resources, although these will be analysed in other chapters.

4.1.3. Marine biodiversity and protection

The great length of Spain's coastline, and the fact that this is washed by different seas over a wide latitudinal range, the Bay of Biscay, the Iberian Atlantic, the Mediterranean and the Atlantic islands, means that there is a great diversity of environments, coasts with greater or lesser tidal flow, upwelling areas (Canary Isles, Gulf of Cadiz, Malaga coast, Galicia and Bay of Biscay), coastal currents (Mediterranean and Atlantic coasts), areas of much exchange with the associated structures (eddies in the vicinity of the Gibraltar Straits; filaments on the coasts of the Canary Isles), very stratified subtropical areas (West of the Canary Isles), all of this involving very contrasted biogeographic situations. To this we can add communities of great specific richness, and the presence of very specific environments, such as submarine canyons. In short, all these characteristics confirm the fact that Spain has a great biodiversity in the marine environment and great potentiality with regard to resources. Of the marine ecosystems considered to be of great value as biodiversity reservoirs and protected by law in some regions of Spain, we can highlight estuaries and marshlands and fields of marine angiosperms (*Posidonia oceanica* in the Mediterranean; *Cymodocea nodosa, Zostera noltii* and *Halophila decipiens* in the waters of the Canary Isles; *Zostera marina* and *Zostera noltii* on the Iberian Atlantic coast, and the fields of algae in the intertidal and subtidal areas of the rocky coasts of the Atlantic and the Mediterranean. The coastal area is also rich in birds, some of whose populations are endangered; species of marine mammals are also frequent this area, most of these protected, as well as turtles.

Unlike the terrestrial environment, the network of marine protected areas was very poor until recently. According to data by the WWF in the years 1999, the Network of Marine Protected Areas (MPA) comprised 38 spaces, only 13 of which could be considered to be truly marine, whereas the rest involve protected terrestrial and coastal areas. The recent creation of the Atlantic Isles National Park merits a whole chapter in itself. The same can be said of the classification as Human Heritage of the fields of *P. oceanica* between the islands of Ibiza and Formentera. Furthermore, there are 18 Marine reserves of fisheries interest, managed by the Agriculture, Fisheries and Foodstuffs Ministry, by the respective Regional Autonomies or through mixed management (http://www.mapa.es/). The recent implementation of the Red Natura 2000 has led to a big increase in the number of protected coastal areas, particularly in the regions of the Mediterranean basin and the Canary Isles. Thus, for instance, the Canaries have 22 exclusively marine LICs and 3 terrestrial-marine ones. On the archipelago, there is a total of 172,215.9 ha of marine LICs (Canary Isles Protected Areas Network, 1995; Natura 2000, Canary Isles Regional Govt., 2000). All the protected marine areas, however, are on the coasts, and there are no reserves on the high sea or on the platform in the waters of Spain's exclusive economic area. Neither has the design of the protected areas been homogeneous with regard to territorial design, and the criteria used have not involved consensus among the different regional autonomies, and certain doubt therefore remains in relation to the complementary nature and optimisation of these areas.

There are protection measures specifically related to fisheries, in the form of reserve areas, closed seasons and prohibited areas, minimum sizes, restrictions of the use of certain types of fishing tackle and fisheries quotas for certain types of species (European, national or in regional autonomies). These measures are aimed at the sustainable use of the resources, rather than at the conservation of ecosystems in the strict sense. In any case, fisheries and conservation are considered to constitute a binomial that should be jointly developed in order to maintain the sustainability of the activity. Protection measures, in the case of migratory species (e.g. tuna, cetaceans or turtles) should encompass all the geographic ranges of these species, such as what is done with terrestrial migratory species. International regulation or co-operation should be promoted.

4.2. SENSITIVITY TO THE PRESENT CLIMATE

The ocean affects climate and this, in turn, affects the characteristics and dynamics of the ocean. Climatic variations and changes can directly affect the ocean, on varying flows of energy and gasses with the atmosphere, the amount of heat and salts transported (temperature and density), the formation and area of sea ice, and, as a result of all this, circulation. Modifications in evaporation and precipitation patterns, or accumulation-melting in continental ice fields can also make an impact. All these events can cause changes in the thermohaline circulation of the ocean (Broecker 1997, Broecker *et al*. 1999), and heat transport between the equator and the poles will therefore be reduced. This situation could give rise to very rapid climatic changes. They could also have an indirect effect on marine organisms and ecosystems (Fig. 4.3)

A second indirect effect could derive from changes in the arrangement of high and low atmospheric pressures and in wind intensity. This situation would generate change in sea currents and in the distribution and seasonality of these, and also in wave patterns. Changes in hydrodynamic conditions will have a direct effect on ecosystems and marine biodiversity, due to modifications in the distribution of temperature and nutrients in the upper layers of the ocean, in marine primary production, and, in short, the marine trophic network, where our main resources are found – fish, molluscs and crustaceans. Changes in the arrangement of mesoscale structures can influence the survival of the larval stage of multiple species, generating changes in exploited fish populations. An example of the effects of mesoscale structures can be seen in (González-Quirós *et al*. 2004).

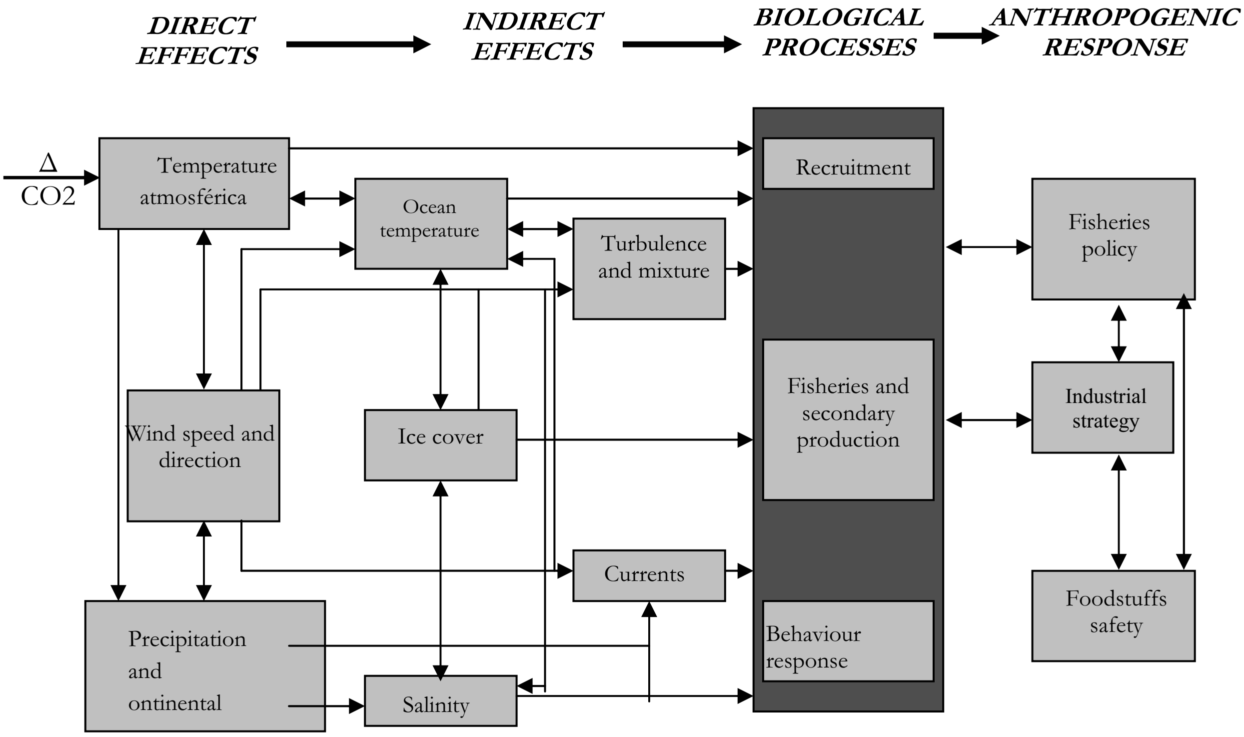

Fig 4.3. *Main channels through which climate change could affect marine populations and the exploitation of these, which are core objectives of the programme GLOBEC of the IGBP (GLOBEC 2003)*

To the modifications that could be generated by climate change, we must add the changes deriving from direct human action, such as the capture of populations of multiple species, and these should be framed within a term of higher rank, Global Change. Without any consistent information, it will be difficult to demarcate the effects of the different causes.

4.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

4.3.1. Impact upon productivity

Analysis of the ecophysiological responses of marine microalgae, the photosynthetic capacity or growth of these, or changes in the ocean associated with CO_2 increases and with Global Warming, provides no clear information in this respect (Beardall and Raven 2004). However, the series of consequences of these effects upon nature probably reflect the complex interactions that can take place between the elements of climate change and other associated factors, such as nutrient availability. The predictable increase in the stratification period (Richardson and Schoeman 2004), or the change in mesoscale processes (upwelling, fronts, coastal currents) could significantly modify the ocean's production capacity, reducing or increasing primary production. This effect could spread to the production of coastal ecosystems, communities of macroalgae or to fields of phanerogams, although processes in the opposite sense might be generated. An increase in CO_2 partial pressure in the atmosphere and in surface waters could lead to increased productivity of the fields of phanerogams or communities of marine macroalgae, as they would be limited by CO_2 availability.

The change in marine productivity would directly affect food availability for the consumers, and in a secondary way, the whole marine trophic network. Certain extensive cultures of filtering organisms, mussels or clams, could be affected; other organisms of great economic interest, like the goose barnacle, could also be affected. If climate change causes a change in the intensity and frequency of waves, populations in the intertidal areas might be affected, some of which may be of commercial interest (Borja *et al*. 2004).

4.3.2. Impact upon species distribution

Associated with changes in the thermohaline properties of the ocean, and with changes in other related processes, we can expect changes in the distribution of many species, both pelagic and benthic ones. A temperature increase would have the direct effect of displacing the geographic ranges of many species (Southward and Boalch 1994, Southward *et al*. 1995, Alcock 2003). The change might speed up or slow down according to the effect of atmospheric changes upon currents or seasonality. Not all the changes will be negative ones, such as reduced species production, and neither will these occur in all parts of the coast. There may be increases in some species, although there is no analysis of the tendencies to be expected according to climate change models.

This displacement will affect mot groups of organisms, both plant and animal, leading to the appearance of species of southern origin, or to the disappearance of northern species. As an associated effect, we cannot rule out the possibility of interactions between the old and new species, biological relationships that have effects that do not directly depend on environmental change. Among the species that could be affected, are the anadromous ones (reproducing in rivers and growing in the sea), salmon, sturgeon or catadromous ones (reproducing in the sea and growing in rivers), eels. Changes are also foreseeable in the geographic range of exploited coastal species, or asociated to changes in abundance of the populations.

4.3.3. Impact upon fish populations. Recruitment and distribution

In the life cycle of exploited marine species, recruitment is a key process and is directly influenced by climatic variability. Variations in atmospheric circulation affect sea currents, and these can modify the transport and survival of larval and juvenile stages. At a greater scale, there could be changes in the trophic chain. Climate changes also indirectly affect marine systems. Marine, primary and secondary production could be affected, which in turn would affect the food available for fish larvae, which would determine the degree of success of recruitment, and, in the medium term, population size (GLOBEC 2003, ICES 2003). Described among the changes are shifts in circulation regimes, sometimes very rapid ones (Hare and Mantua 2002, Chavez *et al*. 2003), which can generate changes in the pelagic community, and even in the benthic one. By way of an example, (Chavez *et al*. 2003) calls them sardine regime and anchovy regime.

Another type of change is related to low-frequency modifications, like the North Atlantic Oscillation (NAO index). Impacts have been described on the growth and recruitment of commercial species of pelagic anddemeral fish in the Northeast Atlantic (Drinkwater *et al*. 2003). Climatic variation (represented by positive and negative phases of the NAO index) govern the alternation of periods of great or little abundance of herring and sardine in the Northeast Atlantic. The positive NAO index has increased in recent years, and we can therefore probably expect associated changes in the future. Associated with the NAO are fluvial discharges that present a relationship with species recruitment in the Mediterranean (Lloret *et al*. 2001, Lloret and Lleonart 2002). Upwelling systems are also associated, in which the production of pelagic species is controlled by processes of nutrient enrichment, food concentration and larval retention (Bakun 1996).

Changes in species can also occur as a physiological response to thermal or saline changes. As an example, it has been suggested that likely changes in the distribution range of species of anadromous fish, given that temperature change can influence proteic synthesis.

Indirectly, there could be alterations in the migration patterns and spatial distribution of certain oceanic pelagic fish (Atlantic bluefin tuna, Albacore among many others) caused by changes in the distribution and abundance of prey. Spanish Albacore fisheries in the Atlantic are seasonal and are exploited during the feeding migration of this species from waters of Madeira and the Azores to western Europe and the Bay of Biscay. The advance of the migration front is associated with a gradual increase in surface temperature. Substantial modifications in the seasonal distribution of the isotherms could affect migratory routes and, indirectly, fisheries in the Bay of Biscay. To the contrary, species of subtropical origin may appear in waters of the Iberian Peninsula (these are already present in the Canary Isles). Some of these species are subjected to sports fishing, and could therefore indirectly affect coastal tourism.

Although less studied, many of the aforementioned factors could affect populations of demersal, or benthic species, and even populations in very deep waters, such as populations typical of canyons. The transport of material from the productive layers of the ocean to the deeper zones may be very rapid. The indirect effects of climate change on exploited demersal populations, however, have not been studied in any depth.

4.3.4. Impact on marine farming

The predictable changes in marine productivity are still quite uncertain. Although changes in phytoplankton productivity associated with hydrographic modifications (Richardson and Schoeman 2004), have been recognised, the predictions of the effects of these upon marine farming are still quite uncertain. The culture of species that provide food supplements should not be affected much, given that modifications in the ration ought to be sufficient to compensate for changes in productivity. Another question is whether environmental change will exceed the physiological limits of the species (dissolved oxygen, temperature, salinity), in which case severe damage could be caused.

Cultured apecies with no food supplement and under an extensive system might be affected. This is the case of molluscs: mussels, clams, oysters and scallops in the *Rías* of Galicia, the Ebro delta and other places on the coast.

Extreme climatic events could have a potential effect on cultures. An intense and continued supply of fresh water in confined areas, such as the *Rías* of Galicia, for example, could reduce salinity, thus causing the mass death of organisms of the benthos, including molluscs in seabed or mussel rafts.

Potentially serious effects upon coastal ecosystems, associated with modifications in hydrographic conditions, but also with increased nutrient dumping by continental waters, involve the proliferation of harmful algae. Among these effects, we should consider changes in the stoichiometry of the dissolved nutrients, as an increase in N/Si relationship favours the proliferation of dinoflagellates over diatomites, and an increase in N/P increases the toxicity of certain species. This proliferation could affect certain sectors, such as mollusc aquaculture, and might also have consequences for human health.

The increase in parasites in the clam and oyster mariculture could be another serious effect of climate change on marine farming. The clam and oyster parasite *Perkinsus* on the coasts of Galicia, possibly introduced by the farming of Japanese clams and oysters, was recently detected and is favoured by temperatures of over 20 ºC. Summertime temperature increases could facilitate the spread of these parasites, along with the damage they cause.

4.4. MOST VULNERABLE AREAS

4.4.1. Vulnerability and Sensitivity of marine ecosystems and fisheries (species and alternatives)

Marine ecosystems are very vulnerable to the multiple simultaneous changes caused by climate change, which mostly affect coastal or shallow ecosystems. A rise in sea level might threaten the communities of marine phanerogams rooted on the seabed between depths of 0.5 m and 45 m, causing underwater erosion and habitat losses or increases, depending on the case.

Changes in seawater temperatures could make many species vulnerable whose temperature limits cause, as has been pointed out, changes in the biogeographic ranges of the species, with a tendency towards the proliferation of subtropical species, making the northern species of our coasts vulnerable. These changes in species distribution do not only influence the appearance of subtropical species, but also increase the risk of invasion by exotic species of subtropical origin which have been accidentally introduced. An example of this is the presence in the Canary Isles of the Australian species *Caulerpa racemosa* var. *cylindracea* (Verlaque *et al*. 2003). Furthermore, seawater temperature affects the life cycles of the species present on our coasts, and, in particular, the intensity and seasonality of sexual reproduction. Variations in recruitment deriving from these changes will cause changes in the demographic balances of the species involved, giving rise to modifications in the composition of communities. Another cause of vulnerability for many species or ecosystems is increased respiratory metabolism, which is sensitive to temperature increase, as this would lead to increased oxygen consumption, and CO_2 production in marine ecosystems and particularly in microbial activity.

The sustained increase in CO_2 partial pressure, on adjusting with the growing partial pressure in the atmosphere, is causing the acidification of the seawater, which can be seen in the detectable decrease in the pH of the water (Caldeira and Wickett 2003). This decrease is expected, within the next 50 years, to be sufficient to clearly reduce, and even halt, the deposition of carbonates in organisms with skeletons or calcified shells, such as bivalve molluscs, reef-forming corals and coccolithophorids among other. This makes them vulnerable. In the longer term, for the CO_2 concentrations expected for the end of the XXI century, there will be a sufficiently intense decrease in pH to initiate the dissolution of carbonates in coastal waters, which will affect CO_2 absorption by the ocean.

Variations in patterns of ocean currents and circulation brought about by changes in the distribution of bodies of water and wind regime caused by climate change will undoubtedly affect the recruitment of all the species depending on these currents to situate their propagules in areas favourable for the growth and survival of the recruits. The vulnerability that this causes in recruitment is difficult to predict, as the current patterns resulting from climate change are subjected to great uncertainty, particularly at local scale.

The pressure caused by climate change cannot be isolated from the direct pressure of human activity on ecosystems. The responses by the ecosystems and organisms to this simultaneous pressure is not necessarily accumulative, and synergic responses could be unleashed that magnify the effects of climate change in relation to those that would occur in ecosystems not subjected to additional pressure. All of this considered, the prediction of the effects of climate change upon marine ecosystems cannot be directly calculated as the sum of the responses of each one of the dimensions of climate change.

The additional pressure concurring with that directly caused by climate change in our country involves: (1) increased transport of nutrients and organic matter to the coast, (2) the impoverishment of fisheries stocks (3) the degradation of the seabed resulting from trawling and mooring, (4) habitat destruction and damage resulting from the development of the coastal area and the proliferation of structures and buildings on the coastline and (5) the increased risk of pollution episodes associated with increased sea transport deriving from the globalisation of the economy.

The most vulnerable ecosystems are therefore those where all these types of pressure concur, and within these, those comprising the more long-lived, slow-growing organisms, like the Mediterranean red coral and the Canary Isles black coral; the fields of algae at certain depths, marshes and fields of *Posidonia oceánica* in the Mediterranean Sea, the fields of *Cymodocea nodosa* and populations of *Zostera noltii in the* Canary Islands, and the fields of *Z. noltii* and *Z. marina* of the Iberian Atlantic coast, and the fields of brown algae found on all of Spain's coasts.

It is particularly complicated to establish which species will be the most vulnerable ones. General criteria can be applied, such as the length of the life cycle, species associated with vulnerable ecosystems, specialist species, but there will always be great uncertainty with regard to the modifications caused by climate change.

4.4.2. Analysis of the vulnerability of coastal and long-distance fisheries

One aspect of the fisheries sector that cannot be forgotten is that part of the decreases in catches could be due to overexploitation, and this should therefore be considered within a higher framework, that of Global Change. But we cannot rule out an interaction between increased fishing capacity and modifications in the environment caused by climate change, which affect the lives of species subjected to capture (Francis and Sibley 1991). Faced with the lack of definitive data, we can only suspect that the loss of some fishing grounds Is due to this cause.

With the exception of species subjected to very fluctuating catches (anchovy, horse mackerel, pacific sardine and japanese pilchard and abadejo de Alaska), most commercial species have been globally subjected to overfishing since 1980. It is estimated that big subsidies will be needed to keep the world fishing fleet afloat, as this is operating at an overcapacity of 30-50%. The present state of the fisheries sector presents a very limited capacity for increase (fig. 4.4.A), given that most of the world's stocks are now at maximum capacity (FAO 2000) (fig 4.4.B).

A B

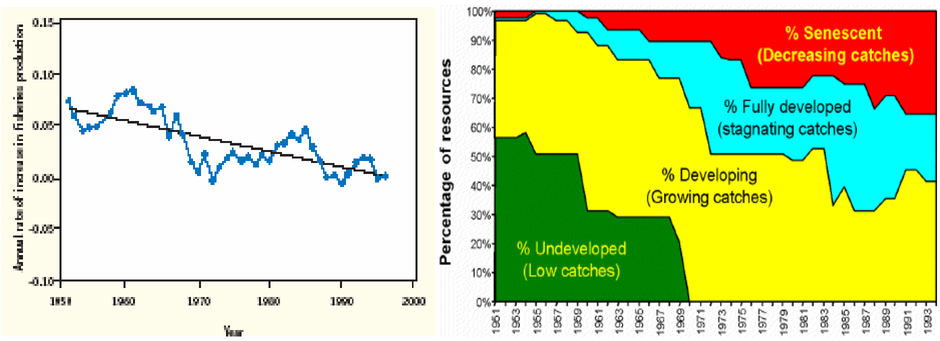

Fig. 4.4. *Global tendencies in world fisheries, A: Annual rate of increase in fisheries production. B: Proportion of stocks being exploited to the maximum capacity or overexploited (FAO 2000)*

There is an evident overexploitation, however, of certain resources, such as depredating fish, throughout the world (Myers and Worm 2003), including in the temperate and tropical Atlantic.

Overfishing of adults can cause evolutionary changes in maturation age, and, in a secondary way, the collapse of stocks (Olsen *et al*. 2004). In any case, the interaction between overfishing of adults, evolutionary changes and changes in the recruitment generated by modifications in mesoscale circulation could bring about the collapse of currently exploited populations of species, or benefit other species. We can only speculate upon which species with long life cycles and low reproduction rates, that is, a low population growth rate, will be most affected.

This is the case of sharks, but the tuna species may also find themselves in this situation.

The aforementioned effects of climate change on recruitment might be the cause of the decline of certain species or could be influencing accessibility to traditional areas (Beare *et al*. 2004)

4.4.3. Analysis of the vulnerability of keystone organisms in the marine environment

Keystone species are those that organise or structure ecosystems. Among these are architect species which, due to their morphology or degree of development, create new environments that can be used by other species, or species which, due to their interspecific relationships, are capable of altering the trophic networks within which they are framed.

Species of marine phanerogams, which form meadows constitute one of the significant cases on Spanish coasts. The role they play ranges from sediment fixation to protection of the coast from waves and storms to providing habitats to sustain the recruitment of a large number of vertebrate and invertebrate species. The fields of phanerogams are registering a sharp decline on Spain's coasts and worlldwide; the global loss rate is 2 % annually. The loss rate of the fields of *P. oceanica* in the Mediterranean is ever higher, with an average loss rate of around 10% per year on peninsular coasts, somewhat (3 % per year) on the coasts of the Balearic Isles. The field of *Zostera noltii* in the Canary Isles are also retreating. Half-way through the 90s, the field was reduced to very few specimens, and was included in the Canary Isles Threatened Species Catalogue (BOCA 23 julio 2991, Decreto 151/2001) with the category of " Endangered".

This loss of area reflects aspects of climate change, such as the generalised tendency towards underwater erosion deriving from a rise in sea level, which uproots the rhizomes of these plants, increasing their vulnerability to storms and intense waves. The degradation of the fields of *P. oceanica* has also been associated with the proliferation of the invasive species of macroalgae of subtropical origin *Caulerpa taxifolia*, accidentally introduced into the Mediterranean, and *Caulerpa racemosa*, introduced through the Suez Canal, which reached the coasts of the Balearic Isles a few years ago and which has recently been located in the Canary Isles (Verlaque *et al*. 2003),where it is associated with fields of *Cymodocea nodosa*, a taxon with the category of "Sensitive to habitat alteration" and *Halophila decipens,* with the category of "of special interest", included in the Canary Isles Threatened Species Catalogue. Although we cannot blame climate change for the introduction of these species, it has been suggested that the increase in sea temperature, as we are dealing with species of subtropical origin, could favour their capacity to exclude the autochthonous flora, in particular the fields of *P. oceánica* (Mediterranean) and *C. nodosa* and *H. decipiens* (Canaries).

It should be noted, however, that in the loss of these ecosystems, other causes intervene which are related to human activity: deterioration of water quality due to dumping from land, the proliferation of structures on the coastline which cause underwater erosion, and the direct impacts of anchors and trawling tackle.

Whereas the re-colonisation time for fields of species of marine angiosperms in the Atlantic is approximately one decade, the recovery of the fields of *Z. noltii* and *P. oceanica*, slower-growing phanerogams, involves time periods estimated at several centuries, and losses must therefore be considered as irreversible with regard to the management of coastal ecosystems. The loss of fields of *P. oceanica* leads to the loss of the species this houses, some of these protected ones, such as the fan mussel (*Pinna nobilis*), a bivalve reaching 1 m long in the Mediterranean, or the fields of *Z. noltii* in the Canary Isles, containing the habitat of species of protected fauna.

Although the long-term effect of climate change upon *P. oceanica* is unknown, recent data suggest that no mechanisms exist to reduce these serious losses in the short term. There is recent evidence of changes in the flowering and fruit and seed production of this species. The compilation and reconstruction of the flowering process of *P.* oceanica in the Mediterranean sea shows two episodes of increased flowering in two years with high temperatures: in the year 2001, following a summer in which seawater temperatures above normal ones were reached, when no seed production occurred, and in 2003, when higher maximum surface seawater temperatures were recorded, which led to the mass production and release of fruits and seeds that are taking root on the seabed in the summer of 2004. If we extrapolate this relationship to estimate the effect of warming of between 1 and 4 ºC, which is expected for the year 2050, it indicates that the prevalence of flowering should increase by between 10% and 40%. This increased sexual production could increase the species' capacity for re-colonisation, although this will never be sufficient to compensate for the losses.

Other communities of marine macrophytes are also retreating, although the role played by climate in this retreat has not been clearly established; this is the case of fields of brown algae of the genus *Cystoseira* in the Canary Isles, which has been repeatedly indicated in reports and projects.[1]

4.5. MAIN ADAPTATIONAL OPTIONS

4.5.1. Alternatives in exploited species, in fisheries structures, fishing species in other areas, compensation with product price, intervention strategies in fisheries

The carrying capacity of the different stocks could be gradually modified as changes take place in the ecosystems. Modifications (increased or reduced production rates) will involve adaptational fisheries strategies. Modifications in reproduction rates will determine changes in the biomass of stocks which will need to be adjusted to the fisheries effort. This becomes complicated in the case of multi-species and fisheries with multiple fishing methods like those in the Iberian Atlantic Region and the Canary Isles. No simulations, however, of possible scenarios have been made. If climate change were to cause stocks to diminish in time, total annual catches would decrease and the fisheries sector would present a long-term tendency towards decline.

The problems deriving from reduced stocks could be camouflaged by price rises and profits for the fishermen. In the long term and economically, the losses may be marginal. If the fisheries sector is to seek maximum economic yield, the systems used for fishing the older age classes (bigger, more profitable fish) might displace or eliminate the activity of other types of fisheries aimed at the capture of smaller-sized fish. Other cases that might arise involve a drastic

[1] "Quantification of marine communities and assessment of the Biodiversity in the El Palmar coastal section"; "Bionomics cartography of the Tenerife coastal fringe (1st part: Teno-Rasca)"; An inventory of the species inhabiting in the reefs and underwater caves in the Canary Isles"; "Study of the biology and ecology of the sea urchin *Diadema antillarum* and of the succession communities in the different pipe-clay areas of the Canary Isles"; "Binomics cartography of the coastal fringe of Tenerife (2nd part: Punta Negra- Roques de Fasnia)

reduction of carrying capacity and the collapse of stocks which would cause a significant reduction of fishing, leading to marginal changes in reproduction capacity which would not affect fishing capacity, or that there would be an increase in the stocks already exploited, or that fishable species would appear that had not previously existed. In the latter cases, the adaptation of the fleets or equipment would be much simpler.

A similar change to stock reduction occurs when some species modify the routes or the seasonality of their migration (Beare *et al*. 2004), and when the fleets that fish them cannot gain access to the stock in this new situation. The mechanisms for adaptation would be similar to those needed when changes in reproduction rates occur. Planning the fleets' activity would require knowledge of the new routes and the reasons for the variations in these, and new interventions would probably be established in European or international relations.

If the objective is the sustainable management of fisheries (Pauly *et al*. 2003) suggest two types of considerations. Environmental ones, which would involve the regulation of subsidies aimed at avoiding overfishing, which in turn, would require the reduction of the fleets. And considerations related to foodstuffs safety, which would involve the discovery of new fisheries or the alternative use of the existing ones, with the problem of affecting other, poor countries, or of transferring environmental damage to their coasts. But we could contemplate alternatives that mix both principles, promoting social equality and environmental regulation. In any case, all this would involve changes in the fisheries regulation systems and agreements among the interested parties.

The establishment of protection areas, in which fishing is prohibited or limited, acting in synergy with the exploited areas, therefore mitigating the effects of fishing on populations or those of environmental change, is a strategy that should be consolidated (Castilla 2003). Thus, the sustainability of a functional and diverse ecosystem, in which the resource species develop their life cycles, would be favoured (Pauly 2002). Advances are being made in the holistic vision of fisheries, and consideration is being given to changes in the ecosystem containing the populations subjected to fishing (Bostford *et al*. 1997), and to anthropogenic influences (physical changes in the ocean resulting from climate change, habitat destruction, pollution, harmful algae blooms).

4.5.2. Adaptation strategies in marine farming

The establishment of new species farming, both of animal and plant ones, could constitute an adaptational response to changes in the environment. But we must keep in mind the dangers posed by the introduction of foreign species for breeding to autochthonous populations and to the ecosystems that contain these. Parasite control of introduced species should be a priority. Parasites introduced with certain farming species can cause damage to the existing ones, especially if their response increases with a temperature rise. The principle of caution should always be applied to prevent the introduced species from escaping from the established controls and from becoming established as invasive species.

Establishing the sustainable carrying capacity of the ecosystems in which the cultured species are introduced, as well as the influence these can have in the environment could constitute a basic adaptational measure aimed at sustainable production. Weather and coastal environment forecasts providing sufficiently timely and accurate warning of possible extreme climatic events (torrential rains that reduce salinity in the environment), together with action procedures, would enable the damages to be limited.

4.5.3. Strategies for the preservation of keystone species

There seems to be a pressing need for species preservation, given the influence of biodiversity on the ecosystems' capacity for resistance and absorption of changes generated by external environmental pressure. In this respect, the preservation of keystone species plays a vital role, given their capacity to affect the structure and functionality of the ecosystems.

Although the number of ecosystems studied on Spanish coasts from the functional point of view is low, and has therefore not been well established, reducing the pressure therein appears to be the best adaptational decision. Apart from the influence of environmental change, we must consider the protection of spaces where these species are safe from human pressure and production, tourism and recreation-related activities, or from development and population growth in coastal areas. The definition of a network of marine protected areas (MPA) in waters of the Exclusive Economic area should take these criteria into account, along with those related to the complementary nature and uniqueness of these spaces, in order to promote conservation and sustainability (see (Palumbi 2001, Castilla 2003).

4.6. REPERCUSSIONS FOR OTHER SECTORS OR AREAS

The increase in the flowering of harmful algae, but also of urticant animal species, such as siphonopophorid jellyfish during warm months is at least partly related to an increase in water temperature and in organic nutrients. This can be troublesome for the tourism sector. Increases have been detected in the flowering of toxic dinoflagellates in coves of the Catalonia coast and in the Canary Isles and of jellyfish in the Mar Menor. There may be more sightings of this kind in the future. The effects of this upon tourism cannot be estimated, but it seems logical to think that it would restrain demand. Increasing our knowledge of the causes thereof and correcting these if possible would be the best adaptational strategy.

Water quality in tourist or production areas could be affected by urban or industrial dumping, which are not directly related to climate change. Changes in local circulation caused by this could alter the current situation. The best adaptational option is to establish and correct these emissions.

4.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

4.7.1. Relationship between warming of the sea and the role played by this as a carbon sink

For time scales of less than 1,000 years, the ocean is the main deposit of carbon dioxide. Atmospheric CO_2 of natural origin and that produced by the burning of fossil fuels are only a small fraction of that found in the sea and in sediments. Approximately 35% of anthropogenic emissions of CO_2 in the last 100 years has been absorbed by the sea. Relatively small adjustments in ocean circulation could significantly affect the amount of CO_2 in the atmosphere, even if the emissions of anthropogenic origin were to become stabilised. If stratification increases in the oceans, water convection will cease and the deepth mixing mezcla profunda will be reduced. CO_2 will not be transferred to the deeper layers of the ocean, the storage capacity of which will therefore be limited.

Another negative factor will be the change in pH caused by the dissolution of the CO_2 itself; this could displace the CO_2 – bicarbonate balance, limiting the ocean's CO_2 storage capacity (Feely *et al*. 2004). Effects associated with the reduced pH would involve: 1) reduced calcification in organisms with carbonated skeletons, which would limit the long-term (sink) withdrawal of dissolved carbon and 2) the potential elevation of the lisocline (depth limit at which carbonates are dissolved), which might favour the dissolution of carbonates accumulated in the sediment; in extreme cases, which cannot be ruled out, the lisocline would rise to the surface, which would cause rapid and radical emission of CO_2 into the atmosphere, thus increasing the greenhouse effect.

Although they have not yet been quantified, positive change in biogenic carbon storage would increase CO_2 absorption and reduce the greenhouse effect.

4.7.2. Seasonal changes in winds and recruitment

We have already mentioned the described effect of changes in the NAO and recruitment, whether through a direct relationship (effect on larval transport) or indirect (interaction with the prey community).

4.7.3. Sea level rise and coastal communities

The rise rates in sea level are sufficiently slow to allow most species to make significant changes in their distribution ranges. On rocky costs, this would involve the colonisation of higher areas, on exposed sedimentary coasts, and if the sediments were to be rearranged, no appreciable changes in communities could be expected, except in those where erosion can occur (see the case of *P. oceanica*). The areas corresponding to estuaries or coastal lagoons will possibly be the ones most affected. The impossibility of re-siting sediment deposits could cause the disappearance of certain environments, or the modification of others, through salinisation. In these conditions, the distribution area of some communities could easily be restricted. Birds might be among the organisms affected.

4.7.4. Interactions between fisheries and climate change

Changes and tendencies related to catches appear to be related to a previous increase in fishing, due both to technological capacity and to the bigger fleets in many countries. We could therefore consider that they are the result of Global Change (GC), rather than climate modifications. In spite of this, there is increasing evidence that, at least during larval stages, changes in coastal circulation, thermohaline conditions, productivity and availability of prey might be responsible for the tendencies observed.

The problem becomes exacerbated when we are dealing with multispecific fisheries. To the responses by each species we must add the existence of interactions among different species, which are not well-known at present. There is a need for more in-depth study of the concept of the fisheries ecosystem (Large Marine Ecosystem) (Sherman *et al*. 1992), and to acquire information that provides us with a more complete view of the synergic effects linking fisheries, climate change and species interactions.

4.8. DETECTING THE CHANGE

4.8.1. Time series of oceanographic variables

Different types of information are available on the variability related to climate change in the North Atlantic basin. Analyses based on temperature observations in the XX century in relation to the calory content of the surface layer of the water (Levitus *et al*. 2000, Levitus *et al*. 2001), of the origin or thermohaline properties of the Atlantic (Curry *et al*. 2003) are a good example. The

study of data series at key points also reinforces the idea of a change in oceanic conditions, such as decreased salinity in deep arctic waters (Dickson *et al*. 2002).
The detection of changes in temperature and salinity are based on the existence of databases over prolonged time periods. The extension of the data series conditions these studies and their capacity to make predictions of future variations. But circulation variability also has an influence, as well as the alterations that can be caused by climate change itself, as both mechanisms can give rise to the advection of the waters in different areas.

Using as a reference the series of COADS (1844-2000) of surface temperature in the Bay of Biscay, certain oscillations can be appreciated in the last century. A surface temperature increase from 1900 to 1960 was followed by a decrease up to 1980. Since then, the increase has been continuous and accelerated up to the present (Southward and Boalch 1994, Planque *et al*. 2003). It is in this framework that we should interpret the higher values detected on our coasts in recent years and which are shown in table 4.1. In short, there is very consistent information relating to surface water temperature increases around the Iberian Peninsula, of approximately 0.4 – 0.5 ºC per decade. Changes have also been detected in intermediate and deep waters, a fact that tallies with the results obtained in studies covering a greater geographic range.

Table 4.1. *Temperature increase rate (ºC per decade) and salinity at points close to the coasts of Spain, with an indication of the length of the time series analysed, situation, depth and reference.*

Site	Situation	Length of the series (years)	Depth (m)	Rate of (ºC decade)	Increase (psu decade)	Author
Bay of Biscay	English Channel	1860-1990	Surface	0.06		(Southward and Boalch 1994)
Bay of Biscay	Ocean	1870-1990	Surface	0.13		(Planque *et al*. 2003)
		1970-1999	Surface	0.6		
Bay of Biscay	Ocean	1972-1993	Surface	0.66		(Koutsikopoulos *et al*. 1998)
Donostia (San Sebastian)	Coast	1947-1997	Surface	-0.062		(Borja *et al*. 2000)
Santander	Ocean	1992-2002	10	0.60	0.04	(González-Pola *et al*. 2003) (Cabanas *et al*. 2003a)
		1992-2002	200	0.54	0.084	(González-Pola *et al*. 2003)
		1994-2003	900-1000	0.1	0.06	
Asturias	Coast	1993-2003	10	0.43	No tendency	(Llope *et al*. 2004)
	Ocean	1993-2003	10	0.16		(Llope and Anadón 2002)
La Coruña	Coast	1990-2003	10	0.53		
Vigo	Coast	1994-2000	200	0.28		(Cabanas *et al*. 2003a)
Murcia		1996-2001	200	**	0.54	(Vargas-Yáñez *et al*. 2002a)
Malaga	Coast	1992-2001	10	0.2		(Vargas-Yáñez *et al*. 2002b)
	Coast	1914-2001	200	0.2		
Balearic Isles	Coast	1994-2001	200	0.2	**	(Vargas-Yáñez *et al*. 2002a)
Gerona	Platform	1974-2001	3	0.4		(Salat and Pascual 2002)
			80	0.25		
Mediterráneo	Ocean	1959-1989	2000	0.04	0.01	(Bethoux *et al*. 1990)
Subtropical Atlantic (24,5 N)	Ocean	1957-1993	800	0.09		(Parrilla *et al*. 1994)
	Ocean	2001-1993	100	0.57		(Vargas-Yánez *et al*. 2004)
			400	0.4	0.07	

Future predictions speak of sea surface warming in a range slightly lower than the modelled changes in atmospheric temperatures (see chapter on climate), in consonance with a balanced radiative balance between atmosphere and ocean. The increase would be greater in summer and on the Mediterranean coast, where there could be, depending on the emission scenario, a 4 degree increase in the last third of the century. For the same reason, we can expect warming of the North Atlantic Central Waters that washes Spain's coasts (ENACW). A visualisation of the foreseeable increase in surface temperature in the Northeast Atlantic can be seen in fig. 4.5 (Alcock 2003), based on the predictions of temperature rises generated by the NOAA-CIRES for around 2025.

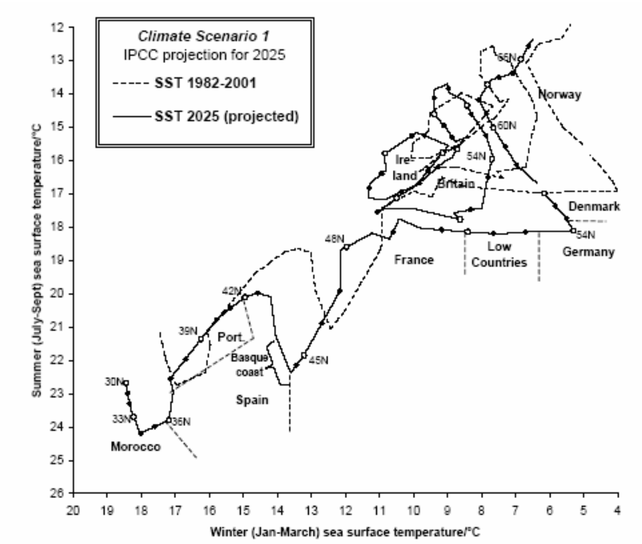

Fig.4.5. *Projection of sea surface temperature on the Northeast Atlantic coast in summer and in winter (taken from (Alcock 2003)*

It should be considered that the temperature increase resulting from the reduced winter mixing, caused by surface warming, could cause an upward tendency. The expansion of the tropical eddy detected (McClain *et al*. 2004) might be an indication of this process.

Long-term variations in salinity are less evident, due to the high interannual variability.. Furthermore, there is a lower number of databases containing this variable. Salinity is a magnitude that is very much related to the evaporation-precipitation balance, to inputs from rivers and water convection. As an example, in the Bay of Biscay and the adjacent Atlantic area, salinity oscillates according to the presence of water of subtropical origin (poleward current) or subpolar waters in the area. Depending on the balances, salinity anomalies occur which are displaced in the upper layer of the different Atlantic areas. This decadal variability is reflected in the surface data on salinity in the Atlantic at our latitudes (Dickson *et al*. 1988, Hudges and Lavín 2003) and has been associated with wind forcings (Cabanas *et al*. 2003b), constriction of the subpolar eddy due to a negative NAO (García-Soto *et al*. 2002).

In spite of these limitations, existing data indicate a slight increase in both surface and deepwater salinity (table 4.1). This is the tendency detected in the whole North Atlantic at our latitudes (Curry *et al*. 2003).

Predictions of changes in salinity are more difficult to make than those related to temperature, as precipitation is one of the factors at play. The distribution of changes in precipitation is irregular in space and throughout the annual cycle, and changes in inputs should not be very significant. In this panorama, evaporation should be estimated in order to get a clearer idea.

4.8.2. Sea level time series

The determination of changes in relative sea level is a complex task. In spite of this, there is evidence of an increase in sea level at global scale and of the causes thereof (Miller and Douglas 2004), and data also exist of variations at specific points of the Spanish coast (Cabanas *et al*. 2003b, Miller and Douglas 2004, Marcos *et al*. submitted). Sea level has risen by around 1.5 mm per year in the last century. Ice melting has contributed, with about 0.4 mm annually, thermal expansion with around 0.8 mm a year and terrestrial movements account for the rest (Douglas *et al*. 2001). The rise in relative sea level has increased in the last few decades, and is currently estimated at 3 mm per year.

4.8.3. Change in climate forcing

Little information is available on the changes in circulation and seasonality in the oceanographic conditions of Spain's coasts. Empirical evidence derives from the analysis of meteorological series, fundamentally of the distribution of centres of high and low pressures in the Atlantic (NAO index), and of winds influencing coastal currents.

Variations have occurred in the last 100 years in the NAO; these have been notoriously seasonal, with a predominance of a positive winter NAO in the last 25 years (http://www.cpc.ncep.noaa.gov/data/teledoc/nao.html). These modifications have been associated with changes in the intensity of coastal circulation in the North and Northwest of the Iberian Peninsula (García-Soto *et al*. 2002), or with modifications in winds, surface sea temperature and with riverine inflow (Planque *et al*. 2003). All the changes generated by modifications in the NAO can alter sea circulation at large scale, and therefore biological activity in the Iberian environment.

Changes were detected in the intensity and duration of winds in the last decade of the XX century in comparison to preceding decades, in particular an increase in south-westerly winds on the coast of Galicia (Cabanas *et al*. 2003b) and a summertime decrease in easterly and north-easterly winds on the Cantabrian sea (Llope and Anadón 2002). These values coincide with the increase in downwelling values after 1997 compared with the values for 1958-1976 and are duplicated, (no tiene coherencia en español) coinciding with high turbulence (Valencia 2004). Changes have also been detected in the seasonality of winds (Cabanas *et al*. 2003b, Llope *et al*. 2004). All these changes have led to reduced spring-summer upwelling in the Northwest (Lavín *et al*. 2000) and North (Llope *et al*. 2004) of the Iberian Peninsula. (Lavín *et al*. 2000) calculate reduced upwelling by approximately half between the 70s and the 90s of the last century.

Based upon information on barometric changes predicted by the UCLM model, changes related to seasonality are to be expected. In the last third of a century, the pressure gradient between the Greenland-Iceland high pressure nuclei and the Azores may be reinforced in winter. Consequently, there could be an increase in westerly and/or northerly winds. The response by the ocean would involve reinforcing the currents passing the Iberian Peninsula towards the poles, and a foreseeable advance in the termination of these. In summer, when upwelling events predominate, the changes would be inverted, with pressure increases in the North and decreases to the South of the North Atlantic, which would be that of the pressure gradient, giving rise to generally gentler winds. In the ocean, this would be seen in less intense upwellings on the west coast of the Peninsula, and also in the North. Furthermore, this would involve an advance in finalisation compared to the present. If the predictions are correct, the tendencies that have been detected will become prolonged in the future.

4.8.4. Signs of Climate Change seen in Biological Responses

(Gregg *et al*. 2003) based on satellite data, described an average increase in chlorophyll at high latitudes of the Atlantic, and a slight increase at medium latitudes. Using another methodology and data on phytoplankton abundance (based on data from SAHFOS) (Richardson and Schoeman 2004) concluded that abundance of phytoplankton is decreasing in areas of the Atlantic with warm mean temperatures, whereas it is increasing in the cold areas; among the warm areas are the Bay of Biscay and the coast of Galicia; this is possibly occurring in other warm seas. Information based on time series, both in the Cantabrian sea and the Mediterranean appear to back this up, although the series available are short and phytoplankton variability is high, thus hindering any irrefutable conclusions.

Changes were noted in the abundance of zooplankton species in the North of the Bay of Biscay from 1930 to 1990 (Southward *et al*. 1995) and in communities of pelagic copepods in the North Atlantic (based on data from SAHFOS), including the coastal waters of the North of the Iberian Peninsula (Beaugrand *et al*. 2000). This modification in the composition and size of zooplankton organisms has affected cod recruitment in the North Sea (Beaugrand *et al*. 2003). Given the positive relationship between the abundance of phytoplankton and of herbivorous zooplankton in the North Atlantic detected by (Richardson and Schoeman 2004), we can expect a reduction of zooplankton in the aforementioned areas of the Peninsula. Changes in the seasonality of hydrographic processes have had an influence on the abundance of zooplankton in the Atlantic (Beare and McKenzie 1999), and on the phenology of species or groups, causing trophic decoupling among these (Edwards and Richardson 2004).

The reorganisation processes generated by climate change can give rise to permanent changes, as can be seen in the relationship between the abundance of *C. finmarchicus* and the NAO. Since 1989 the abundance of this species has declined in the North Atlantic (Fromentin and Planque 1996, GLOBEC 2003) probably due to the reduction of the hibernation areas of copepodites V.

There are few publications dealing with climate-.related changes in the composition of pelagic communities on Spanish coasts. In the Cantabrian sea (Villate *et al*. 1997) detect changes in the abundance of copepods, although the time lapse studied is very short, and (Llope *et al*. 2004) have also observed changes in the abundance of copepod species. Depending on species, there may be a continued increase or decrease, or a sudden increase in abundance. Similar responses are being observed in the Mediterranean (Molinero 2003).

During the last century, changes have been detected in the abundance and distribution limits of species (spread and retreat) living on the coast, associated with environmental changes (Anadón 1983, Southward *et al*. 1995). Although there are recent data on the appearance of macroalgae in the warmer waters of the Cantabrian coast (Fernández and Rico, per. Comm.), it is difficult to justify the presence of these species by invoking climate change. The most notable changes have involved the presence of *Sargassum muticum* in some communities dominated by macroalgae. This invasive species has successfully colonised some communities in the N and NW of the Iberian Peninsula, causing changes in the structure of the receptor community (Sánchez *et al*. submitted).

(Alcock 2003) made a prediction of the distributrion of certain coastal species considering their present temperature limits, along with the projection of these in future temperature scenarios (Fig. 4.5). It was shown that climate changes can affect the distribution of many species whose distribution limit is on Spanish coasts. As has already been mentioned, the change could accelerate if synergic effects occurring between temperature and coastal circulation, as these could influence basic factors such as the concentration of nutrient salts.

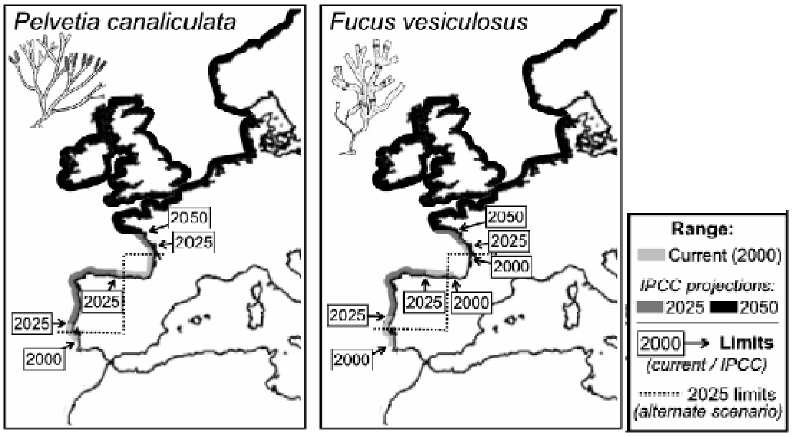

***Fig. 4.5**. Variation in distribution limits of two species of macroalgae according temperature changes predicted by the IPCC models (in Alcock, op.cit.).*

There is evidence of mass deaths of gorgonians and of red corals in the Mediterranean, associated with years of high water temperature (Cerrano *et al*. 2000, Garrabou *et al*. 2001). An increase in sea temperature resulting from climate change could have a negative impact upon these organisms.

Long-lived benthic organisms can provide vital information on the response of organisms to climate change, filtering short-term oscillations and integrating environmental variations. By reconstructing the production and growth of *P. oceanica* for the last 25 years (Marbá and Duarte 1997), deduced a maintained increase during this period, which is probably associated with climate change. It has been possible to reconstruct an increase in flowering frequency in the same species, a very conspicuous phonological sign, in a similar period. This increase can be related to a higher surface sea temperature; the predicted temperature increases could favour flowering in this species. Changes in the area of these ecosystems also present a clear sign of climate change. The upper limit of the fields *P. oceanica* in the Balearic Isles, established with the use of aerial photography, appears to have retreated by around 25 m in the last three decades. This is attributed to underwater erosion caused by the rise in sea level.

The presence has been detected of certain species of tropical and subtropical origin in the Northeast Atlantic, both in the Canary Isles and on the Iberian Peninsula (Brito *et al*. 1996, Quero *et al*. 1998, Brito *et al*. 2001, Stebbing *et al*. 2002). This is interpreted as a response to large scale hydroclimatic changes, whjich would favour immigration of species towards the North. Thus, for example, *Dicologgossa cuneata* and *Boos boops* showed increases in abundance and range at their northern distribution limit in the Bay of Biscay (Poulard *et al*. 2003). The appearance and proliferation of species of subtropical affinity in the Balearic Isles constitute another clear sign of the influence of climate change (Grau and Riera 2001).

There have also been sightings that push the limits northwards of other groups of organisms, such as molluscs and cetaceans (Guerra *et al*. 2002, Williams *et al*. 2002). Unfortunately, the systematic observation series in our country leave much to be desired, particularly in the Mediterranean. Thus, many biological signs of climate change may be appearing without being recorded, and these could provide an early warning of environmental changes associated with climate change. This prevents accurate predictions of future changes from being made, although the observations made to date can be expected to become accentuated.

4.8.5. Climate change, fisheries and mariculture

Climatic variability in the North Atlantic is attributed to decadal and long-term fluctuations governed by atmospheric forcings related to the in the North Atlantic Oscillation (NAO). The NAO has been related to the frequency and intensity of storms in the Atlantic, significant wave height, evaporation and precipitation patterns, regional fluctuations in temperature and salinity, etc. These hydrographic changes have a great impact upon marine ecosystems and fisheries production (Parsons and Lear 2001, Drinkwater *et al*. 2003). There is abundant information on the relationships between the NAO index and catches or recruitment of exploited species by Spanish fleets on our coasts; the anchovy in the Bay of Biscay, the Atlantic tuna or the recruitment of the sardine in Galicia and the swordfish in the Atlantic (Santiago 1997, Borja *et al*. 1998, Riveiro *et al*. 2000, Borja and Santiago 2001, Guisande *et al*. 2001, Borges *et al*. 2003, Mejuto 2003). Something similar has been observed in recent years in the Canary Isles, with the greater abundance of *Sardina pilchardus* (Carrillo *et al*. 1996).

Demersal fish (cod, haddock, whiting, saith) are also influenced by the NAO. The 60s (with good recruitment rates) coincided with periods in which the NAO persistently remained at negative values. In the 90s, the yields of these gadiform species declined to the verge of collapse, coinciding with the change of the NAO to a positive phase at the end of the 80s and the start of the 90s. Although the specific processes linking recruitment and environmental factors during these phases are as yet unknown, global correlations have been established between the tendencies of stocks, the NAO and sea temperature (ICES 1999), and relationships have also been demonstrated that are governed by changes in zooplankton (Beaugrand *et al*. 2003). Given the predictions that the NAO index will present an upwards trend, future changes in the same sense can be expected.

Apart from the general influence of the NAO, the influence of other processes at smaller scale has been noted, and these appear to act in a multivariate way on catches and recruitment of the sea species caught. Among these, the following phenomena have been described: upwelling in Galicia and the Cantabrian, slope currents in the North and Northwest of the Iberian Peninsula and slope currents associated with fresh water inflow – Ródano, Ebro – in the Mediterranean, filaments of the Canary isles upwelling, transport in Gibraltar, eddies in the Cantabrian, temperature changes or turbulence. Among the species studied that present some type of relationship with these conditions, are pelagic species – mackerel, anchovy, horse mackerel (Lloret *et al*. 2001, Sabatés *et al*. 2001, Borja *et al*. 2002, Lavin *et al*. 2003, Lloret *et al*. 2004), o demersal ones –hake- or benthic ones –dory, Norway lobster- (Sánchez *et al*. 2003a, Sánchez *et al*. 2003b, Fariña *et al*. in press). The transport of the larvae of many ecploited species by currents, and the dispersal or concentration of these, have very important potential effects (Sánchez and Gil 2000, Sabatés *et al*. 2001, González-Quirós *et al*. 2004, Lloret *et al*. 2004), although detailed study thereof has only recently begun.

The effects of changes in hydrodynamic factors at mesoscale referred to in the 90s do not appear to have had any great impact in community structure in the short term (Poulard *et al*. 2003, Sánchez and Serrano 2003).

One of the most notable variations that has taken place on Spain’s coasts and which affected some fisheries is the change in the distribution of spawning or migration areas of some species. In recent years, the anchovy in the Bay of Biscay appears and lays its eggs further North, and at different times of year than previously (Borja, com. per.), and this phenomenon occurs parallel to an increase in catches of anchovy and sardine to the North of the North Sea (Beare *et al*. 2004). There are indications of changes in migration routes and in the seasonality of certain age classes of tuna fish (e.g. Albacore *Thunnus alalunga*) situated further North than in previous periods. In the Canary isles, this affected the seasonality of fisheries as well as the catches, and therefore, the fisheries effort applied to other species (Carrillo *et al*. 1996).

Changes in the abundance of tuna fish could affect certain recently developed tourism activities, such as sports fishing. The appearance of other species of tropical origin (marlin), subjected to sports fishing on the coasts of the Canary Isles, and in the North of the Peninsula, could have a compensatory effect. But no information is available regarding the importance of both of these: the number of boats working professionally, the added value of the catches, the amount of people temporarily employed in this activity, among other socioeconomic components.

The reduced catches of Atlantic salmon detected in the North of the Iberian Peninsula might be a reflection of changes in temperature and marine circulation. We have no capacity, however, to determine the intervention of other components, such as the pressure applied by fishing in the sea and in rivers, or the effect of pollution in rivers on populations.

There is little available information on the direct effects of climate change on mariculture. There is evidence that changes in the intensity of the summer upwelling are associated with the quality (% meat weight in relation to total weight) of mussel culture in Galicia (Blanton *et al*. 1987). Given the predictions of reduced primary production (see previous sections), changes in farming yields are to be expected. We can also expect modifications in the growth and physiological state of the cultivated organism.

But there is evidence of indirect effects, due to the action of harmful algae blooms (HAB), which can affect some cultured species or the marketing of these or human health. Although the spread of these could be due to transport by humans, their prevalence could also be associated with water warming, which would favour their increasing appearance.

Since 1976, when cultured mussels in the Rías of Galicia, which had been fed on toxic phytoplankton, caused numerous cases of intoxication causing paralysis in several European countries, these blooms have been recorded and studied. After 1982, new cases of intoxication caused by molluscs were recorded, in this case of the diarrhoeic type. This time, the identity of the culprit species was known. The human response might have been confused with bacterial infections, in which case we would not be dealing with a new case.

Given that the dynamics of phytoplankton populations depend upon water dynamics, changes are to be expected therein. It has been suggested that an increase in the intensity of summer upwelling, a consequence of increased winds, associated with changes in the NAO index caused by climate change, could lead to an increase in the booms of dinoflagellates, such as *Gymnodinium catenatum* (Fraga and Bakun 1993, Garcia *et al*. 1997, Hallegraeff and Fraga 1998, Gómez-Figueiras and Reguera 2004).

Detected recently on the coasts of the Mediterranean and the Canary Isles are species of toxic benthic dinoflagellates of the genus *Ostreopsis* (*Ostreopsis* cf. ovata) which could be considered as tropical (Vila *et al*. 2001). In waters of the Canaries, another typically tropical dinoflagellate has been observed, *Gambierdiscus* (Fraga, pers. comm., Ojeda, unpublished data), which produces one of the strongest toxins known. Its tropical nature appears to indicate a future increase in abundance caused by global warming, and a northward expansion of its range and probable entry into the Mediterranean.

The change in conditions could be associated with the reduced abundance of certain toxic species. This appears to be the case of *Lingulodinium polyedrum* on the coasts of Galicia, which has caused the three oldest cases of red tides described in scientific literature. It is now considered to be a rare species (Fraga 1989).

Apart from the effects on farming, species of harmful algae could cause other types of economic damage. Many very attractive beaches for tourism on the Mediterranean and the Atlantic are affected by frequent blooms of algae, which tourists take to be dirt. Since the first observation of the dinoflagellate *Alexandrium catenella* in waters of Catalonia in 1987(Garcés *et al*. 1999), the mass presence of this has become a frequent phenomenon in the western Mediterranean (Vila *et al*. 2001). The centric diatom *Atteya armatus* causes brownish-green colouring on some tourist beaches in the Canary Isles. An increase has been described in the recurrence and intensity of this in the last 4 years (Ojeda 2004).

The projection of future changes should follow criteria similar to those described in this section. Increases in warm waters species, and decreases in cold waters species, with the corresponding changes in abundance and distribution limits will be expected. More difficulty is involved in predicting the time lags within which these changes will occur, as well as the intensity of these.

4.9. IMPLICATIONS FOR POLICIES

4.9.1. Fisheries policies

Given that climate change can cause changes in the production of stocks, local or regional impacts could be extreme. Climate predictions will have to be considered in long-term yield projections of stocks of commercial species, and in relation to management systems and social and economic structures (markets, structures, investment), in order to adjust to the new conditions, which will possibly involve less available resources.

The present objective of fisheries resources management is the sustainability thereof, and it is believed that the greater effect on the size of stocks is the result of fishing. Climatic variability is believed to affect the short and medium-term abundance of some stocks of pelagic species and should be considered in management plans in order to avoid collapses in abundance, and losses, not strictly in relation to fisheries, but to investments associated with the sector. There are EU proposals to implement plans for the recovery of certain species (hake, Norway lobster) on the Iberian Atlantic coast and continued overexploitation is believed to prevent the recovery of stocks.

The new ideas relating to the management of stocks of exploited marine species propose basing this management on multispecific fisheries, as an intermediate step towards a type of management based upon the ecosystem. The concept of "ecological approach" can be subjected to two complementary interpretations: consideration of the effects of fishing on the ecosystem, or consideration of the responses by ecosystems to fishing. This management is developed through two channels: the production of adaptational models based on easy-to-obtain information on stocks, or through indicators of the state of quality of the ecosystems based on the definition of desired levels of conservation. All of these approaches lie within the framework of Large Marine ecosystems (http://www.edc.uri.edu/lme). Apart from the objectives related to maintaining and recovering resources in the fisheries sector, this approach contemplates other objectives related to the protection and recovery of habitats that are complementary to fishing, the maintenance of biodiversity, or ones related to the economic and social sectors (Castilla 2003). All of these aspects will affect a great deal of institutions, local, regional, national and European ones. As much of Spain's fisheries production comes from long-distance fishing grounds, outside community waters, policies relating to international co-operation will also be affected.

Placing more emphasis on product quality, with ecological labelling aimed at ensuring sustainable fishing could also help to attenuate impacts and to support fishermen within a context of scarcity of resources. These measures will reduce collateral effects in ecosystems and fish populations such as those caused by bycatch and others.

4.9.2. Marine farming policies

The policy on marine farming affects state policies and those of the regional autonomies, because they refer to inland waters. The policy of intense development undertaken in the last few decades should be evaluated, and attention should be paid to changes in productivity, and therefore to yield and sustainability.

Policies relating to the introduction of foreign species should be reviewed in relation to farming, and the principle of caution ought to be applied. The interaction between these and autochthonous ecosystems and species could cause unforeseen negative changes if they were to escape human control. Furthermore, if there is insufficient sanitary control, there might be an increase in the number of pathogenic organisms, which would cause serious damage to the pre-existing mariculture.

4.9.3. Coastal development policies

Coastal development policies will affect the EU, the central administration and the regional autonomies. Local administrations will also be affected. Increased human activity in coastal areas may cause many of these to be affected by change, particularly by a rise in sea level. The combined effect of hydrographic changes and increased human activity could contribute to the development of harmful algae blooms, thus affecting resources and human health.

The prevention of erosion and the negative consequences of this for ecosystems should be considered with regard both to maintaining beaches and other elements of interest for the tourism sector, and to conserving ecosystems that are vulnerable to changes in sea level. We should therefore consider the impacts of the construction of infrastructures and housing on the coast within the context not of current impacts, but rather of those generated by a rising sea level. The maintenance of sediment balance should govern coastal development policies. The impacts of climate change on the demand for infrastructures should also be considered.

There is much social pressure to develop new and better port facilities, both commercial ones and marinas, and moderation is called for in this respect in order to avoid impacts upon coastal sediment dynamics (e.g.: The construction of the future Granadilla Port in the Canary Isles). All facilities should have the necessary infrastructures (tanks for collecting sewage waters, oils, etc) to avoid the impact of the wastes that these facilities generate.

There seems to be a need for control networks dealing with the development of toxic or urticant blooms, which have already been set up in some Regional Autonomies, and these should be implemented immediately in order to establish a basis for future decision-taking. This need has been recognised in other countries suffering from problems related to certain potentially dangerous species for our farmed species or to humans (for instance *Pfeisteria* in the USA).

4.9.4. Ecosystem conservation and management policies

This will involve all levels of administration, from the EU to the administrations of the Regional Autonomies. Given the precedents of the direct effects of human activity and the foreseeable modifications caused by climate change, there appears to be a need for a policy for the protection of exploited fish populations and of coastal ecosystems, which are the ones that will foreseeably be most effected by the changes. Network design criteria should be considered relating to the complementary and unique nature of Marine Protected Areas (MPA). The population should become involved and profits should be generated through complementary conservation and fisheries strategies, along with the necessary dissemination of these.

4.10. MAIN RESEARCH NEEDS

4.10.1. Detecting changes in oceanic conditions

One of the main deficiencies in marine sciences in Spain, which have been highlighted in numerous scientific forums, involves the scarcity of time series for the marine environment, in a permanent observation system similar to the meteorological one, either with direct sampling using boats or with the use of buoys and satellites. This is much more important if we are to document and predict the response by the ocean to climate change.

This deficiency has been partially corrected through initiatives by some institutions, the Spanish Oceanography Institute, State Ports, AZTI, or initiatives by other institutions (CSIC - higher centre of scientific research - in Blanes, CSIC in Vigo, Oviedo University in collaboration with the SOI), or private centres (San Sebastián Aquarium), and even personal initiatives (Josep Pascual en L'Estartit, Girona). The establishment of a well planned and co-ordinated observation network, suitably funded, with appropriate guarantees of quality and which covers the observation needs of the marine environment in the long term is an unavoidable necessity. To this end, an Oceanographic Data Centre would be needed.

There is also a need to increase the existing oceanographic databases and to promote the compilation of the information available in existing databases or of that generated by research projects, past or future ones, financed by the Public Administration. This would allow for more rational and efficient use of oceanographic data, to respond more effectively to our compromises with international programmes dedicated to climate change in the ocean, and to make significant contributions to the management of our resources. Co-ordination with certain international initiatives would be desirable. An example of this is the Open-source Project for a Network Data Access Protocol (DODS) (http://helium.gsfc.nasa.gov/Data/portals/dods/index.html) linked to oceanographic databases, (http://helium.gsfc.nasa.gov/Data/portals/dods/param_search/OCEANS.html), or the French one, co-ordinated by IFREMER that attempts to monitor ocean climate (http://www.ifremer.fr/merseaip//).

There is a need to develop satellite image databases (CREPAC-INTA, IEO, AZTI), and to co-ordinate the way in which these are obtained and stored, and to facilitate the use thereof. Variables such as surface temperature, chlorophyll, altimetry and winds are very useful for analysing change at large scale. Systems similar to the Comprehensive Ocean Atmospheric Data Set (COADS), widely used by the scientific community, which provide specific data on meteorology and sea surface temperatures (SST) for our zone could be of great interest, if rigour and quality are used in their implementation. New long-term control initiatives are also needed, such as the European project FerryBox on the Porstmouth – Bilbao route (http://www.soc.soton.ac.uk/ops/ferrybox_index.phppp), as these provide low-cost continuous data.

The promotion of national programmes for the study of Climate Change and of the responses by ecosystems and marine populations, defined in the International Programmes IGBP (GLOBEC, SOLAS, JGOFS, GOOS,…….) could provide the necessary impulse to fill the many knowledge gaps detected during the drafting of this report.

4.10.2. Atmosphere-ocean interactions and climate system

Given the close relationship between atmospheric and oceanic processes, and their relevance of these in the causes and intensity of Climate, it seems necessary to increase Spain's participation in the study of the interactions between both systems, within the framework of the pertinent international directives and projects. Directives on Research plans should consider the role played by the ocean as a modulator of change in the concentration of greenhouse gasses in the atmosphere, or as a transporter of heat on the Planet.

There appears to be a need to consider changes in wind regimes, given they role they play in forcing many mesoscale processes influencing primary productivity and in the recruitment of multiple species. These changes are associated with climate change.

4.10.3. Relationships between the dynamics of marine ecosystems and hydrographic conditions

As with oceanic conditions, one of the gaps detected is the absence of credible, contrasted and standardised databases on fisheries production, which are very scare in the monitoring of populations or ecosystems not subjected to fishing. Indeed, monitoring is almost non-existent if this is considered in relation to climate change. Analysing inter-species interactions within the framework of the ecosystem in which the species live and recruit, provided this is framed within the context of environmental change, including fishing by humans, would provide information for predicting future change and for designing management mechanisms to adapt the production system, the conservation of resource species and ecosystems.

The behaviour of ecosystems, effects on inter-species interactions, or general changes, depending on whether key species are affected or not, are fields for which very little information is available, but we do know that climate change can cause big changes in ecosystems. The co-ordination of the monitoring networks of biological responses existing in different regional autonomies or in co-ordination with the aforementioned marine environment systems, would provide knowledge practically in real time of the state and tendencies of these ecosystems and would enable us to learn of the effects of climate change.

4.10.4. Metabolisms of significant species and interactions among species

Given the complex functioning of ecosystems, long-term monitoring of the physiological responses of selected species, or phenological cycles (reproduction period and intensity) would enable us to understand the mechanisms of environmental change. Study of certain long-lived species would enable us to reconstruct species response to the change that has already occurred (Marbá and Duarte 1997, Kennedy *et al*. 2001), thus increasing our knowledge of the times and speeds of the changes. Predicting the rhythm of the changes will facilitate adaptational response and the adoption of consistent environmental policies.

Another urgent need involves defining the significance of biodiversity in ecosystem functioning, and the use of this from the point of view of adaptational resources management, in order to satisfy needs related to fisheries through environmental sustainability.

4.10.5. Summary

Table 4.2 summarizes the main foreseeable impacts and the probability that these will materialize. Knowledge on these effects want be a research priority

Table 4.2. *Processes affected by global change in the future in Spain and Probability of occurrence*

Processes affected by global change in the future in Spain	Probability of occurrence
Surface warming of seawater in the future	***
Changes in the salinity of sea water	*
Changes in carbon dioxide exchange between the atmosphere and the ocean	**
Changes in mesoscale circulation	**
Rise in sea level	***
Changes in the distribution limits and abundance of plankton species	***
Changes in the distribution limits and abundance of benthic species	***
Effects upon larval survival and the recruitment of exploited species	**
Effects upon marine productivity	**
Changes in the composition and dynamics of communities	**
Effects upon the presence of toxic or stinging species	*

**** Very high probability; ** Medium probability; *Little probability*

4.11. BIBLIOGRAPHY

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5. IMPACTS ON PLANT BIODIVERSITY

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ABSTRACT

The direct impacts of climate change on plant biodiversity will occur through two antagonistic effects: warming, which lengthens the period of activity and increases plant productivity, and the reduction in water availability. The projections of the model Promes indicate the first will prevail in the north of the Iberian Peninsula and in the mountains, while the second will affect mainly to the southern half of Spain. Hence, the “mediterraneisation” of the North of the Peninsula and the “aridification” in the South are the most significant tendencies for the next century. The more severe scenario involves a climatic displacement of almost a whole bioclimatic belt, particularly in the South, whereas in the more moderate scenario the change is equivalent to half of the altitudinal interval of a belt. Such displacements exceed the migration thresholds of most species.

The biggest indirect impacts are those deriving from edaphic changes, changes in the fire regime and the rise in sea level. Interactions with other components of global change (land use changes, modification in atmospheric composition) constitute another important potential source of impacts for which evidence is now beginning to accumulate. The modification of the interactions among species (competence, asynchronies, herbivory, pests, invasions) is also being documented, although the dimensions of these kind of impacts is still uncertain. High-mountain vegetation, forests and deciduous thickets sensitive to summer drought, sclerophyllous and lauroid forests in the South and Southwest of the Peninsula and coastal vegetation are among the most vulnerable types. Structural simplification of plant communities and the predominance of local extinction over re-colonisation constitute recurring tendencies identified for most of the expected impacts. The ecological role of plants as primary producers determines that floristic and vegetational changes have direct or indirect influences on most sectors commented in this Report. The loss of floristic diversity is of particular relevance in Spain, given that our country contains a high proportion of Europe’s plant diversity.

Avoiding losses of biodiversity caused by the impacts of climate change requires global responses. The sectorial strategies designed require a broader geographic framework than that of regional or local administrations, upon which they currently depend. The network of protected areas, conservation strategies, ecological restoration, forest management, the regulation of livestock farming and hunting uses, land planning, environmental evaluation and education constitute the policies most involved in the challenge of providing responses to the impacts of climate change.

Future research on the impacts of climate change on vegetation can be structured in three main and interconnected lines: monitoring of current changes, species and community responses to change, and predictive modelling, which should be based on the information reported by the former and on climate projections, to allow the adoption of mitigation measures for the anticipated impacts. Concerning monitoring activities, support for the participation in phenological networks, including aerobiology, for development of applications based on dendrochronological databases and remote sensing approaches is advisable. It is also needed the implementation of long-term monitoring programs aimed to the quantification of floristic and vegetational changes. These programs could be implemented in the network of protected areas and should be representative of the Spain’s biogeographical and habitat diversity. Threatened species and vegetation dynamics after disturbances are issues to be integrated in these programs. Concerning responses to climate change, the effects of the modification of species interactions, identification of functional groups of plants with similar responses and assessment of indicators of climate change impacts on biodiversity are the main issues for research.

Predictive models of the dynamics of the floristic diversity under the pressures of climate change will be the best tools for generating projections, adopt mitigation measures and evaluate their efficiency. An effort is still needed for computerising the data available on Spain's floristic and vegetational diversity. Models must progressively incorporate resolution at landscape and regional scales, fragmentation effects, dispersal and migration species thresholds, indirect effects of climatic change and interactions with other components of global change.

5.1. INTRODUCTION

The objective of this chapter is to evaluate the impacts of climate change upon the plant components of biodiversity in Spain. The dimensions of these climate modifications are based on the projections appearing in Chapter 1. The concept of biodiversity considered is the most common one, which was proposed in 1992 in the Rio de Janeiro Convention on Biological Diversity: "biological diversity is the variety and variability of all types of living organisms and of the ecological complexes they form part of; it includes the diversity within each species, among species and that of ecosystems" (CBD Secretariat 2001), and redefined by Gitay *et al*. (2002) in terms of "the relative numbers and abundance of genes, species and communities or ecosystems". Knowledge of this variety and variability, even in territories as specific as a country with the dimensions of Spain, is far from satisfactory, and neither is that of their different components and levels of complexity (Noss 1990, Heywood and Baste 1995, Purvis and Hector 2000), at the different spatial scales to be analysed. For this reason, an evaluation of the characteristics required by this Report should focus on those components and levels, the degree of knowledge of which allow for a reasonable prediction of responses to climate change like the ones analysed here. With regard to the plant components of biodiversity, we will comment upon aspects related, on one hand, to vascular flora, paying particular attention to endemic and threatened flora, and on the other, to vegetation as a more complex and integrating level of plant diversity.

Plant diversity in Spain: vascular flora

Spanish plant heritage has a very relevant species diversity in the European and Mediterranean context. Around 80% of the flowering plant species in the European Union are found in our country. This richness is due not only to the geographic dimensions of the territory, but also to a combination of factors that include an intricate orography, the variety of climates and microclimates, the mosaicism of lithologies and soils and geographic location. The strategic position of the Peninsula has historically favoured floristic richness therein, due to the fact that, in the different eras in the past, it has served as a migratory junction in the northward movement of North African flora towards Europe, as the western limit in the spread of flora from Southeast Asia and the eastern Mediterranean, or as the southern refuge, acting as a cul-de-sac, when climate changes associated with glaciation periods forced flora towards the warmer southern climes. The accumulation of floristic contingents of different origin has found a suitable context in which to subsist in the noteworthy spatial and temporal heterogeneity of Mediterranean environments (Blondel and Aronson 1999), which, besides, are characterised by the recurrent disturbances, both natural and anthropic, which have favoured the co-existence of species with differentiated responses (Cowling *et al*. 1996, Lavorel 1999).

In spite of the relevance of Spanish flora compared with the surrounding areas, there is still a lack of accurate figures in relation to the species it consists of. The most recent estimates situate the vascular flora (ferns, gymnosperms and angiosperms) at around 8,000 or 9,000 species. Of these, there are around 2,200 in the Canary Isles (Santos 2001, Izquierdo *et al*. 2001), around 1,500 in the Balearic Isles and over 7,000 in the Spanish Peninsula (Médail and Quézel 1997).

The map in Fig. 5.1 illustrates the patterns of floristic richness in the Iberobalearic territory. It is based on the distributions of 1,400 taxa expressed in 10 x 10 km cells of the UTM grid, constituting between 15-20% of the flora in the territory, estimated at between 7,500 and 8,500 taxa (Castroviejo 1995, 1997). The Iberian mountains are seen to have the greatest level of diversity, which is not surprising if we consider the habitat diversity existing therein and the lesser degree of anthropic transformation (Castro *et al*. 1996). Sierra Nevada is the most noteworthy, with 14% of species mapped, followed by several enclaves in the Pyrenees, the Cantabrian, Iberian and Central mountain ranges, the Catalonia-Valencia coastal mountains and the remaining Betic ranges. The plateaus and the large inland endorheic and river catchments tell another story, presenting areas that have been transformed since ancient times and which sustain a lesser variety of habitats for the flora. The analyses carried out on the regional patterns of floristic richness (Lobo *et al*. 2001, Rey and Scheiner 2002, Pausas *et al*. 2003) show that the main determining factors are those related to environmental heterogeneity (relief, substrates and climates). Plant species richness is also positively related to temperature and to water availability (Lobo *et al*. 2001, Pausas *et al*. 2003).

This image of total floristic diversity becomes modified when its different components are separately examined. Fig. 5.2 shows the richness patterns of ferns, a group of vascular plants suffering from particular conservation problems in the Ibero-balearic territory. In this case, added to the importance of mountain areas, among which we can highlight the Pyrenees, is the oceanity factor, which conditions geographic richness patterns.

Plant diversity in Spain: endemic, rare and threatened vascular flora

Apart from its total floristic richness, Spain has been highlighted as the Mediterranean and European country with the highest number of endemisms (Médail and Quézel 1997, Gómez Campo 2002; table 5.1). There is a direct relationship between the endemicity percentage and the degree to which a determined flora is threatened. Indeed, the levels of endemicity combined with the sensitivity to diversity loss were the criteria used to designate biodiversity *hot-spots* at a worldwide scale (Médail and Quézel 1999, Myers *et al*. 2000), among which the Mediterranean basin or the Canary Isles were included. Although there are Spanish plant endemisms that occupy large areas and are not threatened at all, the high endemic densities present a clear correspondence with those areas richest in threatened flora.

The figures for Iberobalearic endemic vascular plants, including species and subspecies, are at around one thousand five hundred (Pita and Gómez-Campo 1990; Moreno Saiz and Sainz Ollero 1992, Sainz Ollero and Moreno Saiz 2002). Although this number will increase as the drafting of *Flora iberica* progresses, the endemicity percentage of the flora could be expected to remain at around the known value of 15-20%, one of the highest exclusivity figures in the Mediterranean environment (Table 5.1). The Canary isles, with around 550 endemisms (20% of total flora and almost 30% of the native flora), are in a privileged position, due to their historic biogeographic isolation, their little involvement in the pleistocene glaciations, and to an abrupt relief which provides varied habitats and climates.

Analysis of the areas with most stenochorous species once again highlights the grid for Veleta, in the Sierra Nevada, as the one with the highest level of diversity, followed by other from Ibiza, the Sierra de Algeciras mountains, the Segura-Cazorla massif and a whole series of enclaves scattered throughout the Betic ranges (Castro *et al*. 1996).

A total of two thirds of the species included in the Spanish Red Book of vascular flora (Bañares *et al*. 2003) are endemisms (321 over 478; Moreno Saiz *et al*. 2003). The distribution of these indicates the large amount of stenochoric species existing on the islands or in the mountain areas. The map in Fig. 5.3 shows the 10 x 10 km cells of the UTM grid in which populations of some of the taxa included in the Red Book have been detected. Of approximately 5,600 grids of this size covering Spain, a total of 727 contain at least one of the taxa dealt with. The distribution of these shows clear similarities with the provincial map of the most threatened species presented on the Red List (Aizpuru *et al*. 2000).

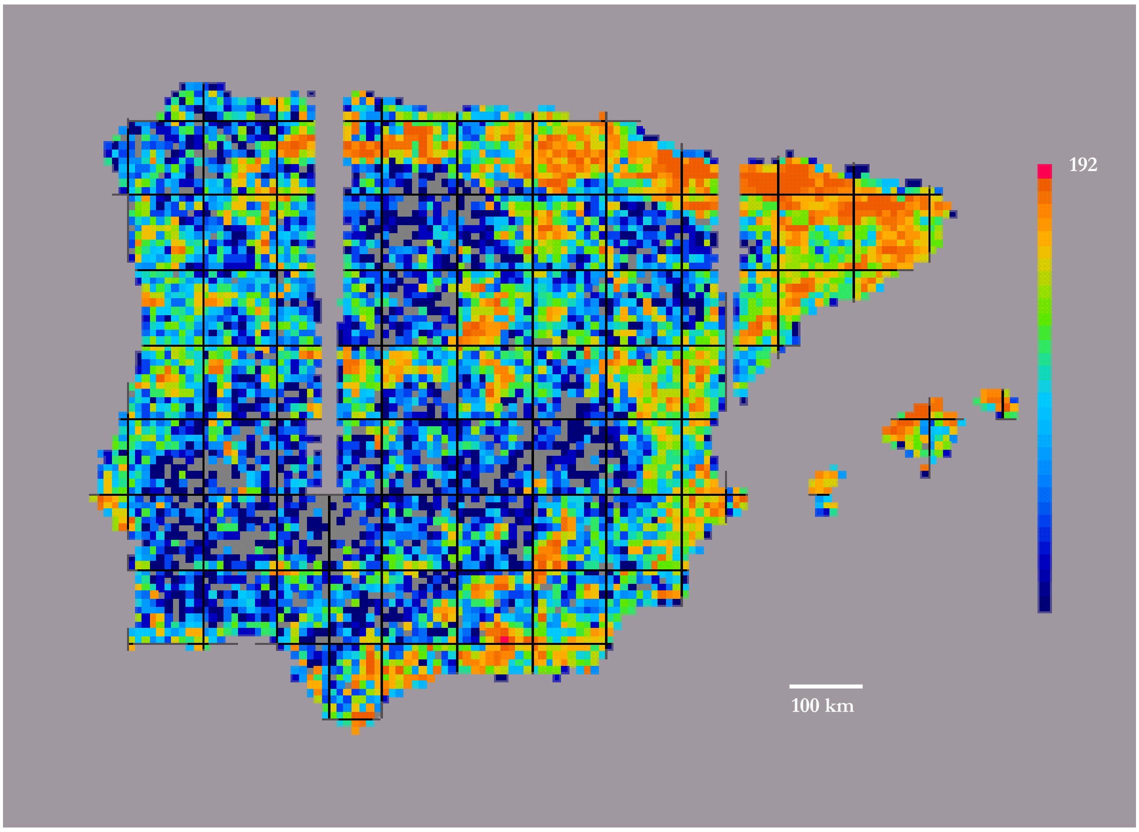

Table 5.1. *Number of species of vascular plants and endemisms in Spain and neighbouring countries (modified from Médail* and *Quézel 1999)*

Table 5.1. *Number of species of vascular plants and endemisms in Spain and neighbouring countries (modified from Médail* and *Quézel 1999)*

Country	***Number of species***	***Number of endemisms***
Ex–Yugoslavia	5000	320
Algeria	3150	320
Spain	8000-9000	1300-1500
France	5000-6000	900
Greece	5500	1100
British Isles	1443	17
Italy	5600	730
Morocco	4200	900
Portugal	2600	114
Tunisia	1800	40

With regard to floristic originality, the Canary Isles have been considered as a biodiversity "*mini-hotspot*" (Mittermeier *et al*. 1999), with endemicity percentages at around 30% if we consider only the native flora (Santos 2001; Machado 2002) and the vast majority (58%) of endemisms restricted to one single island (Humphries 1979, Izquierdo *et al*. 2001). The map of the 171 species studied on these islands shows that there is practically no grid on the Canaries without at least one endangered plant species (Moreno Saiz *et al*. 2003).

The Balearic Isles also has endangered and critically endangered species on the five biggest islands, although with a lower occupation density. The Pythiusian islands (Ibiza and Formentera) are relatively well represented, as are the Serra de Tramuntana mountains and certain points of the coast of Majorca. This pattern coincides with those identified in recent studies of the Iberobalearic flora threatened or protected by the Habitats Directive (Domínguez Lozano *et al*. 1996, Sáez and Roselló 2001, Bañares *et al*. 2003). Clear evidence of the importance of the islands in general and of the risks their flora is faced with, is what we can see on the map 5.1.3, in spite of the small area, the Columbretes Isles, Alborán Island and the National Park of the Atlantic Islands of Galicia, all of which contain endangered species.

With regard to the Spanish Peninsula, Fig. 5.3 highlights the importance of the Betic ranges and the Levant for threatened flora. Not only do the Betic ranges have the highest percentage of peninsular endemicity, but also the highest levels of stenochory, with numerous differential species among their main massifs (Sainz Ollero and Hernández Bermejo 1985, Castro *et al*. 1996, Blanca *et al*. 1998, 1999). There is a notable number of grids with threatened flora on the coast and in the mountains of Galicia, the density of which had not been estimated through previous analyses (Moreno Saiz and Sainz Ollero 1992), and which has not been proportionally reflected in Spanish or European conservation legislation (Domínguez Lozano *et al*. 1996). The other mainland Euro-Siberian territories are less clear, or are represented only by vulnerable taxa, as occurs in some sections of the Cantabrian and Pyrenees ranges.

The central Iberian plateaus constitute the areas with the lowest number of threatened plants. This is very much accounted for by the fact that they have been altered since ancient times, and have therefore lost their naturality, but also partly because these are areas with low endemicity levels. (Moreno Saiz and Saiz Ollero 1993). Together with the extraordinary accumulation in the Canaries, the grids show a considerable and noteworthy dispersion of endangered species in many parts of the country. Up to 80 taxa of the Red Book are present in one single 1 km^2 UTM grid throughout Spain; for many of them, this constitutes their whole worldwide distribution, given that they are endemic. Only 138 taxa have a distribution area divided among ten or more grids of these dimensions.

Ibero-balearic endemisms as a whole are more related to intermediate successional stages, and to the particular substrates and biotopes typical of mountain reliefs, than with late-successional communities (Montserrat and Villar 1973, Gómez Campo *et al*. 1984, 1987; Laguna 1999, Melendo *et al*. 2003).

Plant diversity in Spain: vegetation types

Spain's vegetation is also among the most varied on the European continent. Around 90% of the vegetation classes included in European classifications currently in use are represented in Spain (Mucina 1997, Rivas-Martínez *et al*. 2001, 2002). Recent compilations recognise over 2,500 plant associations on the Iberian Peninsula and its archipelagos, the diversification of which allows for the evaluation of the internal diversity of the territories and the geographic differentiation of the respective floristic ensembles.

Among the main patterns recognised in the distribution of most types of peninsular terrestrial vegetation, in first place appears the North-South summer drought gradient, which marks the separation between Euro-Siberian vegetation, which requires summertime water availability, and Mediterranean vegetation. The North and Northwest of the Peninsula, including the Pyrenees and Cantabrian ranges and Galicia, are currently dominated by the former, which spreads, in a fragmented way, throughout the mountain ranges of the North half of the Peninsula. Five sixths of Spain's territory is biogeographically included in the Mediterranean region. A second determinant factor for the vegetation is lithology, which separates the siliceous substrates predominant in the West from the base-rich soils existing in most of the Levant and the South of the Peninsula (Loidi 1999). The occurrence of particular, minority substrates (gypsum, dolomites, ultrabasic rocks, etc.) is among the most important factors promoting the endemicity of the flora (Gómez-Campo *et al*. 1984, Gómez Campo 1985, Heywood 1995). The complex relief, with the associated altitudinal climatic gradients and barrier effects, introduces another level of biogeographic differentiation, in which the transversal orientation of the main mountain ranges must be highlighted. Although these may have hindered meridian migration, they have also favoured accumulation of species along ecotones and biogeographic borderlines. Among the main effects caused by relief are the two main peninsular semi-arid areas, the Ebro basin and the Southeast of the Peninsula; the latter contains a noteworthy plant richness of Iberian-North African range (Alcaraz *et al*. 1991). Lastly, the insularity reaches its maximum expression in the originality of the flora and vegetation on the Canary Isles; this includes several classes of vegetation which is either endemic or is shared with the neighbouring archipelagos (Rivas-Martínez *et al*. 1993). The biogeographic sector delimitation of Spain's territories adjusts to these factors (Rivas-Martínez and Loidi 1999a, b; Rivas-Martínez *et al*. 2002).

The main structural types of vegetation on the Peninsula will be summarised in section 5.3.3, along with an evaluation of the corresponding impacts of climate change. Riparian vegetation and wetlands are dealt with in Chapter 4 of the Report.

Recent impacts on plant diversity

At present, Spain's vegetation, except in a very limited number of small enclaves, is, like in most of Europe, the result of a long history of human intervention which has been partially superimposed over climate changes in the recent past, of which the most recent episode is the Little Ice Age (LIA). Among these interventions are extensive deforestation processes, either mass or selective ones, which, together with the extraction of firewood or timber, reached their height at the beginning of the last century, along with the establishment of agricultural or livestock farming uses and the associated transformations. The composition of landscapes shaped by these land uses, interfering with a complex vegetation which only partially adjusted to the latest climate changes, must surely have suppressed those less tolerant components of diversity, but must also have contributed to the joint maintenance of other components that now characterise much of the biodiversity of European countries in general and the Mediterranean ones in particular.

Over the last few decades, other impacts on vegetation have been recorded, which are part of the so-called global change and which are actively contributing to the deterioration of biodiversity. With regard to Spain, on one hand we can highlight changes in land uses, partly caused by rural abandonment, and on the other, the intensification of farming systems. The abandonment of the agriculturally less productive land (almost 2% in the last decade, a sixth of which has been changed for urban construction and infrastructures), together with the reduction or abandonment of extensive livestock farming, and firewood and charcoal extraction, have favoured the spread of shrublands and semi-natural pastures, and the growth of forest, all of which has also been promoted by reforestation policies (over 4 Mha in the last 40 years). The consequent accumulation of fuel in woodlands has led to the occurrence and spread of fires, as is described in Chapter 12. In turn, intensified uses affect biological diversity through promoting processes of eutrophication, pollution, erosion and desertification, the reduction and fragmentation of certain habitats in some cases and the homogenisation of landscapes in others, etc. Furthermore, anthropic transformation and the development of trade and transport are believed to be favouring the introduction of exotic species, thus providing opportunities for biological invasions. This concurrence of factors has not yet led to the extinction of vascular flora to such a considerable extent as in other biological groups, but it does probably contribute to increasing the proportions of flora threatened (Greuter 1991, 1994).

In a parallel fashion, in the last few decades, there has been an increase in the number of protected natural areas, which currently represent around 6% of the national territory (Gómez-Limón 2000, Reyero 2002), and this area will rise to 23% with the Special Conservation Areas established within the framework of the Habitats Directive (Orella 1999, Morillo and Gómez-Campo 2000). The geographic distribution of this future network of protected areas (Orella 1999) is concentrated in the mountain areas, leaving big gaps on inland plains and depressions, and in many coastal areas; the imbalances among territories are equally notorious.

The coincidence in time of the changes in land uses with the first symptoms of climate change makes it particularly difficult to delimit the corresponding impacts. The changes in uses and especially abandonment, favour in some cases the spread of more competitive types of vegetation, and in others, there is evidence of adjustments by the vegetation to recent climate change, which could not be expressed while the pressure of the respective land use was maintained. In the case of flora and vegetation, we must also consider the superposition of other effects deriving from changes in atmospheric composition, which have a direct influence on plants, such as increases in CO_2, tropospheric ozone, aerosols, atmospheric deposition of nitrogen oxides, etc.

In the drafting of the Atlas and Red Book of Threatened flora (Bañares *et al*. 2003), an individualised evaluation was made of the risk factors for each of the 2,223 populations studied, which allowed for analysis of the threats recognised for the most vulnerable component of the flora. The results obtained from the field surveyers are synthesised in Table 5.2. Although the level of detail is now greater (populations instead of taxa), the most commonly indicated risk factors generally coincide with the previously described ones (Gómez Campo 1996; Domínguez Lozano *et al*. 1996). Whether it be a verified threat or a potential risk, overgrazing is the most quoted factor (almost 40% of the populations), closely followed by human transformation of the land, traditional gathering and plant collecting, or competitive displacement by other plant species. Likewise, results indicate that the reduction, fragmentation and degradation of natural and semi-natural habitats constitute the main risks for species persistence. What is noteworthy, however, is that no consideration has been given to serious threats such as competition by introduced exotic plants or climate change. The latter, however, has been identified as a threat in Sierra Nevada (Blanca *et al*. 2002) and in the Canary Isles (Marrero *et al*. 2003).

With regard to the potential risks dealt with in the Red Book, the table shows a high level of coincidence on indicating many of the disturbances associated with climate change or susceptible to being exacerbated by it (Houghton *et al*. 2001): droughts, fires, storms, floods and other geological risks. Although these disturbances are inherent to most of the ecosystems comprising the endemisms and threatened flora, their presumable greater incidence in the future under the available scenarios of climate change constitutes a certain risk factor for floristic diversity.

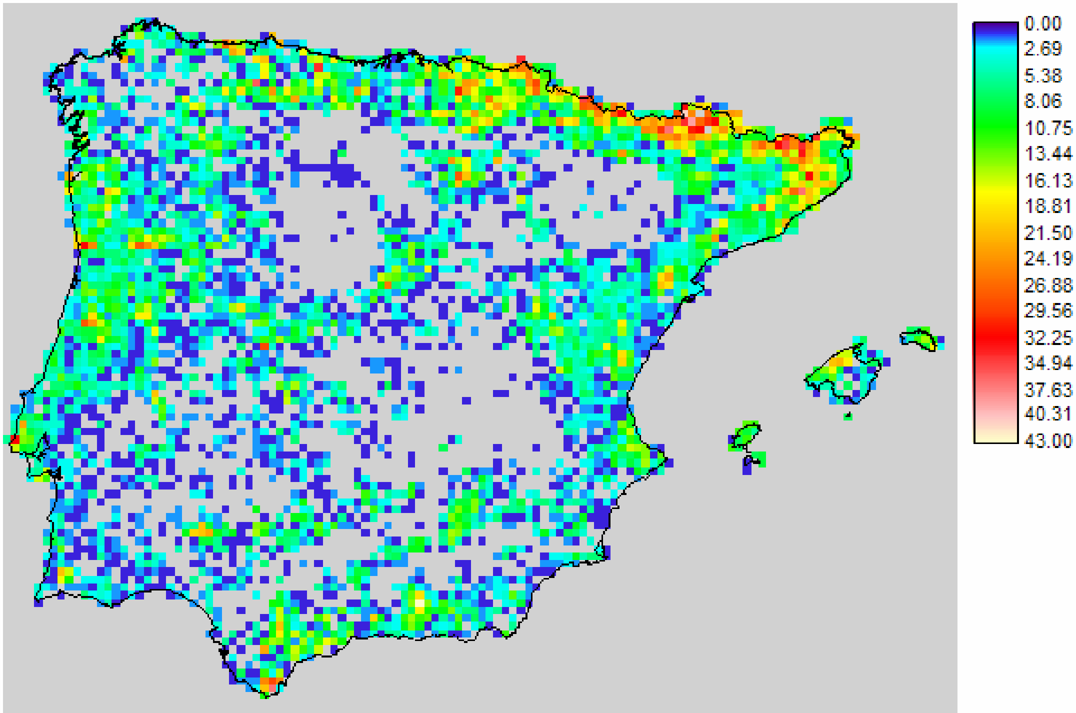

Fig. 5.2. *Patterns of floristic richness of ferns in 10 x 10 km grids for the Iberian Peninsula (Moreno Saiz* and *Lobo in prep.).*

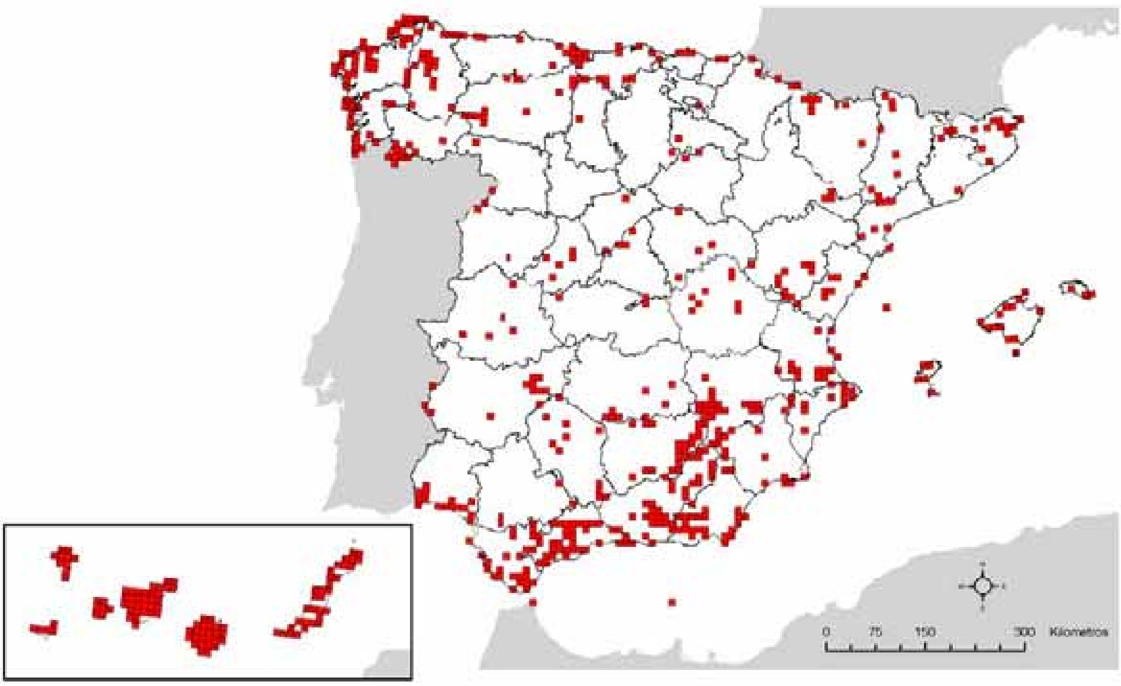

Fig. 5.3. *UTM 10x10 km grids in which populations of threatened species have been detected.*

Table 5.2. *Most mentioned potential threats and risks for the threatened vascular flora included in the Spanish Red Book, expressed as the proportion of the total number of populations sampled (2223) of the 478 species considered (Moreno Saiz et al. 2003).*

Threats	Number of populations affected	% of the total of populations studied (2223)
Threats resulting from human action		
Shepherding	851	38
Trampling and *artificialisation*	656	30
Traditional collecting or gathering	426	19
Threats of biotic origin		
Natural plant competition	493	22
Depredation	475	21
Little ecological plasticity	441	20
Poor reproductive strategy	224	10
Threats resulting from the type of development		
Improvement of roads network	527	24
Construction of new roads	324	15
Housing development	210	9
Indirect threats		
Improvement of access by vehicles	398	18
Improvement of access by the population on foot	328	15
Improvement of access to neighbouring lands	239	11
Potential accidents due to:		
Droughts	1192	54
Rockfalls	995	45
Fires	806	36
Storms	696	31
Floods	499	22
Landslides	475	21
Volcanic activity	448	20
Avalanches	426	19

5.2. SENSITIVITY TO THE PRESENT CLIMATE

5.2.1. Current relationships between climate and vegetation

The relationships between vegetation structure, primary productivity and plant distribution, and climatic elements have constituted one of the classical themes of geobotanical literature (Woodward 1987, Blasi 1996, Fernández-González 1997). Numerous authors have proposed climate classifications that attempt to fit the former to values of the latter, which have generally been derived from standardised weather records. Almost all these classifications coincide in the importance of temperature variables (mean or minimum temperatures, positive temperature or temperature sums, duration of the period of vegetative activity, etc.) on one hand, and variables related to annual or seasonal water availability (precipitation, water balance, ombrothermal indices) on the other, on climatically fitting the distribution of plants or vegetation types. Multivariate analyses of these relationships reflect similar results (Moreno *et al*. 1990, Gavilán and Fernández-González 1997, Gavilán *et al*. 1998). Although the fits obtained are mainly correlational, general models have been designed which are capable of predicting at a global level the distribution of the main physiognomic vegetation types (Box 1981, 1996; Woodward 1987, 1992; Prentice *et al*. 1992, Haxeltine *et al*. 1996), which prove the existence of causal relationships, among which the most obvious ones derive from the tolerance of plants to extreme temperatures, minimum duration of the vegetative period, or the fit of the life cycle and dependence on productivity in relation to water and energy availability.

In Spain, one of the most detailed climatic classifications available, especially with regard to its relationship with vegetation types, is the one developed by Rivas-Martínez and collaborators (1997, 1999, 2002, www.globalbioclimatics.org). This classification makes use of different summertime ombrothermal indices to separate Mediterranean climates from the temperate ones (without summertime water deficit). The bioclimatic belts corresponding to each type of macroclimate are defined with the use of positive temperature summations (thermotypes) and annual ombrothermal ratios (ombric types). The units of this classification will be applied in the following section (5.3.2 and 5.3.3) to the evaluation of the projections of climate change.

Whereas the classifications mentioned are based on climatic regularities, irregularities or interannual climatic fluctuations (Rodó and Comín 2001), merit special attention because of their effects upon reproduction (Herrera 1998), recruitment rates and plant mortality (Moreno *et al*. 1999, Quintana *et al*. 2004), in the disturbance regimes (Chapter 12) and in the dynamics of community diversity (Figueroa and Davy 1991, Peco *et al*. 1998). This type of effects, documented in different types of habitats and species, although with much less detail, are superimposed over average climate tendencies, and could interfere with these or even camouflage them (Hulme *et al*. 1999).

5.2.2. Past climate changes and changes in vegetation

Since the appearance of Mediterranean type climates, between 3,2 and 2,3 MaBP ago (Suc 1984), climate change have become the norm during the Pleistocene, which, during the two million years it lasted registered between four and six main glaciation cycles, interrupted by several other interglacial periods, which were warmer, generally more humid, and, as a whole, over ten times shorter than the former. It has been estimated that, during the glacial periods, global temperature fell by between 6 and 8 ºC, more sharply in the boreal and polar latitudes than in the tropical ones. These periods, however, appear to have been characterised by great climatic irregularity. Apart from the development of big icecaps at high and medium latitudes, the sea level fell (180 m in the Mediterranean at the height of the last glaciation, around 18,000 years ago), as did global precipitation, due to the decrease in air humidity, although the evidence in this respect is less clear, and there may have been considerable regional variation.

The effects of glaciation periods on the flora and vegetation were seen in migration towards lower latitudes and local or regional extinctions. During the interglacial periods, the flora, quartered in southern refuges, advanced latitudinally, at different speeds according to species and periods, of between, for holarctic trees, 5-50 km/century for most zoochorous species and up to (10)50-200 km/century for the anemochorous ones (Huntley and Birks 1983, Huntley 1991). *Pinus, Corylus* (150 km/century) and *Alnus* (up to 200 km/century) are among the most rapid genera. Vegetation re-composition had different dimensions according to latitude, as in the boreal and temperate northern territories, re-colonisation occurred following the withdrawal of the ice, whereas in medium temperate latitudes, there was a predominance of displacements (latitudinal and in many cases also longitudinal), and in the southern temperate latitudes there were processes of accumulation and species packing, as well as altitudinal movements of the flora, favoured by the rejuvenation of the relief of these territories during the alpine orogeny. The extinction mainly affected the flora of tropical affinities that had predominated in medium latitudes until the end of the Tertiary. Following the first two glaciations, practically all this contingent had become extinct in Europe, where the transversal orientation of the main mountain ranges had hindered meridian migration more than on other continents. Little is known of the changes that took place in the previous interglacial periods, but in some of these, the Mediterranean pulses appeared to have had a great influence (Pons and Quézel 1985). There is evidence that during the previous interglacial period, temperatures were reached of up to 4 ºC higher than at present.Although the Quaternary did not last long in evolutionary terms, speciation processes must have played an important role, and were promoted, apart from climate variations, by the fragmentation of the species' refuge areas, the orographic diversity and lithology of these, and processes of poliploidy, which operated effectively in different groups of angiosperms during interglacial re-colonisation. With regard to the Mediterranean basin, speciation was much more active among the "modern" Mediterranean element than among the "pre-Mediterranean" one (see 5.3.3.3). Thus, the glacial periods were more effective with regard to determining extinction, and those that provided the necessary evolutionary time. During the interglacial periods, there were mainly processes of floristic redistribution, in which coasts, valleys and mountains played an important role as refuges and migration routes.

Since the height of the last glaciation, around 18,000 years ago, the climate has become progressively more temperate, but in a non-uniform fashion both in the temporal and spatial sense. In the initial phases (14,000-10,000 years BP) acute warming episodes took place, during some of which the big spread of sclerophyllous vegetation can be appreciated (Pons and Reille 1988, Burjachs and Juliá 1994), which was interrupted by sudden cooling periods such as the old and recent Dryas. The final deglaciation began immediately afterwards, through the Holocene, with moderate temperature changes, but big changes in rainfall (Pérez-Obiol and Julià 1994, Burjachs *et al*. 1997, Jalut *et al*. 1997, Jalut *et al*. 2000, Davis *et al*. 2003). During the first quarter of the Holocene, there was progressive warming, but within a framework of moderate rainfall, at least in the western Mediterranean. In the second quarter (approx. 7,500-5,000 years BP) there was a considerable increase in rainfall, while temperatures could have been up to 2ºC higher than at present during the warmer phases. In the third quarter, up to 2,500-2,000 years BP, rainfall decreased, especially in the southern and eastern half of the Peninsula, and in North Africa (Cheddadi *et al*. 1998); to the contrary, in Europe and the North of the Peninsula, a moderate cooling period was only detected. From half way through the Holocene, in particular in the coastal regions, the first impacts upon vegetation by Neolithic humans can be noted, which will also become generalised inland during the last two thousand years, while the aforementioned tendencies continue with lesser oscillations, such as the medieval cold and warm episodes or the Little Ice Age.

The changes in vegetation, documented mainly with the use of paleopalynological records, have responded with diverse phase differences among territories to these climatic changes, which were probably not uniform. In Europe, the first post-glacial warming periods caused the displacement of the tundra regions, theretofore dominant, northwards and towards the high mountain, and the spread, first of pines and birches, and then of hazel and other deciduous fagaceae. Similar tendencies have been recorded in the North of the Peninsula (Peñalba 1994, Allen *et al*. 1996); to the contrary, in the western Mediterranean, the steppes and open conifer forests (*Pinus* and *Juniperus*) that dominated the lateglacial landscapes (Pons and Reille 1988, Pérez-Obiol and Julià 1994) remained relatively unaffected during the first quarter of the Holocene. Only then did progressive migrations begin, of both deciduous and sclerophyllous elements, slower and later in the South, until, with increased rainfall, there was a big spread of the different deciduous forest formations. Mesophytic forests began to withdraw in favour of sclerophyllous, and in general xerophytic, vegetation half way through the Holocene, when, especially in the South, aridification was accentuated and the present Mediterranean climate became established in the basin. In the North of the Peninsula, however, there was little or no

Mediterraneisation, given that the spread of the beech was prolonged up to the last quarter of the Holocene (Peñalba 1994).

Paleopalynological analyses only reveal a small fraction of the species involved in the changes, but they show that the responses by the vegetation to climate change have relatively slow phases, which can be prolonged for several centuries, and in which the migrations take place and mechanisms for resisting the change are activated by the pre-existing vegetation. But there are also alternating phases of changes in dominance that can be very rapid, especially when synergies occur with certain disturbances or other causes that can break the resistance of the theretofore dominant species. For example, changes in the fire regime associated with intensified aridity and with anthropic intervention in some cases, have accelerated the substitution of deciduous forests by sclerophyllous vegetation or conifer forests, or the alternation among the latter two in different parts of the South and East of the Peninsula (Riera and Esteban 1997, Carrión *et al*. 2001, 2003). These rapid changes in dominance can take place in less than one century, once the immigration has occurred. Equally rapid is the spread of the herbaceous and woody vegetation associated with anthropic changes in the territory as a result of livestock farming or agricultural uses, which have been superimposed over the environmental changes of the last few millennia, thus complicating the interpretation thereof (Pons and Quézel 1985, Reille and Pons 1992, Carrión *et al*. 2001). The migration processes probably were more limited in the Mediterranean territories than in more northern latitudes (Huntley 1991), due to the abundance of refuges and to physiographic obstacles. For these reasons, and within the framework of the individualistic responses by the species to climate changes (Moore 1990, Graham and Grimm 1990, Huntley 1991), there has been a redistribution of the flora that has determined the current rigid geographic compartmentation observable in many types of plant communities.

5.3. FORESEEABLE IMPACT OF CLIMATE CHANGE

5.3.1. Types of foreseeable impacts upon flora and vegetation

As was documented in Chapter 1, meteorological records from the last few decades are beginning to show clear signs of climate change in Spain, although these are still difficult to resolve with the necessary spatial and temporal clarity. The thermic signal is clearer, with an estimated increase for the last third of the century of between 0.3 and 0.6ºC per decade, with notable differences between territories, seasons of the year and maximum and minimum temperatures. The signs of pluviometric changes are less evident due to their complex patterns of spatial and temporal variability (inter and intra-annual). There appears to be evidence of reduced rainfall throughout most of the Peninsula, except in the North and Northwest, where winter rainfall might also have decreased. It cannot be said, however, that interannual variability is globally increasing, although symptoms have been detected both of greater pluviometric variability in the South and Southeast and a higher seasonal concentration of rainfall. The analysis of dendrochronological series suggests an increase of thermal and pluviometric variability during the last century (Manrique and Cancio 2000). Local reductions of snowfall and of snow cover have also been indicated. As a whole, this weather signal can be seen in an average warming rate of between 1-1.5ºC, equivalent to an altitudinal displacement of around 200 m in the limits of many species.

5.3.1.1. Direct impacts

Projections of climate change for the end of the century in south-western Europe, documented in Chapter 1, indicate a generalised temperature increase, with certain significant seasonal differences; reduced water availability, caused by warming and by the reduction and seasonal redistribution of rainfall; and increased climatic variability, above all in relation to temperature regime and to extreme heat events, although this is not so evident in the rainfall regime.

The direct consequences of temperature increase for plants will initially involve an extension of the vegetative activity period, on reducing the restrictions caused by low temperatures. In the absence of hydric limitations, biological activity will increase, which will lead to increased potential productivity. The adjustment of the phases of the plants' development cycle to the new temperature regime will bring about phenological changes, both in wild and agricultural species, and those that are to be most expected hereinafter will refer to foliation, flowering and fruiting dates, or delays in leaf abscission in deciduous species in winter. We could, however, expect different responses according to species and processes, given that the degree of thermoperiodic control compared with other types of control (photoperiod, hydroperiod) is variable, as well as the phenotypic plasticity (Kramer 1995). Thus, not all species will be able to make use of the extension of the vegetative period in the same way (Körner 1994, 1995), which would involve modifications in competitive relations. To the contrary, this phenological advance could give rise to a greater risk of exposure to possible late frosts, which would only have an impact in mountain areas, given that the general occurrence of this phenomenon would be reduced. Furthermore, warming provides the possibility, for the species that are capable of capitalising it, of entering territories from which they had previously been excluded because of temperature conditions. This latitudinal or altitudinal spread will become more effective if the new habitats are not already occupied by other species, or if they are occupied by competitively inferior species. For certain plants, however, especially cold climate ones (high latitudes or altitudes), warming could cause the inhibition of the life cycle phases induced by low temperatures (Körner 1995, Larcher 1995), thus affecting the viability of the populations involved, which might be subjected to serious retreat. Evidence of phenological changes caused by climate change will be commented upon in section 5.8.

The direct consequences of a reduction of water availability are partially opposed to the previous ones, given that they involve reduced potential productivity, which corroborates climate change in the same projections (Chapter 1). The parallel temperature increase will increase net primary productivity even more, on increasing respiration rates. This tendency will favour drought-tolerant plants or those that avoid it, compared with other, potentially more productive ones, and, in extreme cases, it will also favour the structural simplification of the vegetation through reduced height of plant cover. Unlike warming, reduced hydric availability is much more effective with regard to excluding less tolerant species, through impacts on reproduction and recruitment rates, lesions in adult specimens or debilitation and susceptibility to predators and pests. Indeed, in the distribution of Mediterranean flora and vegetation, hydric relations often show greater discriminant power than the purely thermic ones (Gavilán 1994, Gavilán *et al.* 1998).

An increase in climatic variability and in the incidence of extreme events is one of the aspects of climate change that involves the highest degree of uncertainty. If, as the projections appear to indicate, the main tendency involves more frequent late spring heat waves, then the effects of these could exclude the less drought-tolerant species.

In relation to preceding and documented climate changes, including the sharp oscillations of the Alleröd and the last Dryas, the one that is currently occurring is of an extraordinarily abrupt nature. The response capacity of species through micro-evolutive processes will be very limited (Bradshaw and McNeilly 1991), although in certain relatively short-lived genera of plants which have shown great capacity for recent evolutive radiation, responses of this type could be detected. The magnitude of the changes projected indicates that the limits of phenological plasticity of much of the flora will be surpassed in many territories (Holt 1990); furthermore, this plasticity could be restricted in unfavourable environments, such as the Mediterranean and high-mountain ones (Valladares 2001). For the more long-lived plants, apart from the impossibility of producing any micro-evolutive response, we must also consider the difficulty involved in producing acclimatisation responses, at least in adult specimens. Thus, latitudinal and altitudinal displacements will constitute a fundamental response in the readjustment of flora to new climatic conditions, and could attenuate the proportions of foreseeable extinction (Bakennes *et al*. 2002, Thomas *et al*. 2004).

The capacity to migrate under the pressure of a climate change is documented in the Pleistocene for many species (see 5.2.2), but only the fastest ones will be able to deal with the scope of future changes in this way, and only after a variable delay period. Latitudinal displacements will be easier for short-lived species, with good dispersal skills and few demands in relation to appropriate habitat. The latter condition will be a serious limiting factor for many species in current, profoundly transformed and fragmented landscapes (Pitelka *et al*. 1997). Altitudinal migration requires movement of less range, but involves reductions of the area available for those species whose climatic space rises in altitude. There is much evidence of altitudinal and latitudinal movement of flora attributable to climate change (Hughes 2000, McCarthy 2001, Walther *et al*. 2002, Parmesan and Yohe 2003), including lichens (van Hark *et al*. 2002). Whatever the case may be, these movements will involve a radical re-composition of communities. Apart from their capacity for dispersal and their plasticity, other factors that will favour the survival of species in relation to climate change are related to their altitudinal, geographic and habitat amplitude and to the genetic diversity of their populations. Prolonged *in situ* persistence could be viable in certain long-lived species able to take advantage of the temporal windows of opportunity favourable for reproduction and recruitment, or characterised by metapopulation or source-sink dynamics allowing the periodic recolonisation of available habitats (Eriksson 1996).

5.3.1.2. Indirect impacts

Apart from these direct effects, climate change will also have an influence on other factors which in turn will affect vegetation. Among these indirect effects are those involving soil as a physical and nutritional support for plants, those related to the disturbance regime (Pickett and White 1985) and the ones associated with a rise in sea level.

Soil organic matter content is a key factor with regard to the edaphic availability of water and nutrients. The available projections of climate change indicate a generalised reduction of the organic carbon content in soils, as a consequence of reduced rainfall combined with warming. This tendency could become synergically accelerated through interaction with the accentuation of the fire regime, caused by the new climatic conditions, and through erosion, caused both by disturbances and by the reduction of soil organic matter. In the short term, mineralisation of organic matter could rapidly affect certain dependent systems, such as bogs, which would be easily displaced by other types of more productive vegetation. Increasing aridity of the climate and loss of edaphic organic matter would also promote desertification processes, which at present seriously affect one third of Spain’s territory, especially in the South and the East. Lastly, soil salinisation can also occur rapidly, especially on irrigated agricultural land. Increased salt content in surface horizons constitutes a very selective factor for the flora, which responds rapidly in terms of impoverishment because of the low number of species capable of tolerating these conditions. In the areas affected by aridification, the reduction or even the inversion of leaching and the consequent pH elevation could favour the expansion of basophile or indifferent plants, to the detriment of the acidophile flora.

With regard to the disturbance regime, the possibility of a greater frequency of heat waves has already been mentioned. In relation to our latitudes, one of the consequences will be the changes in the fire regime commented upon in Chapter 12. Greater incidence of fires could accelerate replacements among species or vegetation types with different degrees of adaptation to the new climatic conditions, as these will govern the dynamics of post-fire regeneration (Quintana *et al*. 2004, Rodrigo *et al*. 2004). Big or recurring fires could contribute to making the resulting landscapes more homogeneous (Pérez *et al*. 2003), and to initiating degradative dynamics that accelerate the structural simplification of the vegetation, or increasing erosion, which in turn impoverishes seed banks (García-Fayos *et al*. 1995) and soil nutrient availability.

Another consequence of warming will be a rise in sea level, caused by the thermal expansion of the ocean and by the fusion of icecaps and glaciers. Changes in the coastline, in the geomorphological processes of this, in the water table and the associated coastal systems (coastal pools, dunes) will affect the flora and the plant communities depending on them.

5.3.1.3. Interactions with other components of global change

One of the greatest sources of uncertainty in relation to the effects of climate change involves possible synergies and antagonisms with other components of global change, and in particular, with regard to plants, with changes in atmospheric composition and with changes in land use (Moreno and Oechel 1992, Moreno 1994, Moreno and Fellous 1997, Lavorel *et al*. 1998), which should play a modulating role with regard to the direct and indirect effects of strictly climatic changes (Peñuelas 1996, 2001).

Changes in the atmosphere are the main cause of climate change, but these also have independent effects on the functioning of plants. Atmospheric enrichment in CO_2 and the deposition of nitrogenated compounds have a fertilising effect that increases photosynthesis and biological activity in general (Woodward *et al*. 1991, Ceulemans and Mousseau 1994, Strain and Thomas 1995, Körner 2000). The former also improves the efficiency of the plants with regard to water and nitrogen consumption (Peñuelas and Matamala 1990, Peñuelas and Azcón-Bieto 1992), which could attenuate the impacts of aridification, especially from the agricultural perspective (Hulme *et al*. 1999). It has also been shown that it favours advances in flowering and increases flower and fruit production (Peñuelas 2001). Although they were tested in experimental chambers, these effects appear to have limited temporal efficiency due to acclimatisation, to the attenuated responses by adult plants and to the limiting role of other factors, such as water availability (Reichstein *et al*. 2002); their magnitude is diluted on magnifying the temporal and spatial measurement scales, and it is possible that they may have started to enter a stabilisation phase (Peñuelas 2001). Nitrogen deposition is lower in the Mediterranean than in other temperate latitudes, but it could hare a more important effect on plant growth than CO_2. As with the previous case, effects differ depending on species. An example of the antagonisms involved in global change is that whereas CO_2 enriched atmosphere will favour C_3 plants, warming or aridity will favour the C_4 ones, which function better in conditions of high irradiation, high temperatures and low hydric availability (including saline soils).

Warming and increasing concentrations of CO_2 are also known to favour emissions of volatile organic compounds (VOCs) by the vegetation. VOCs have different functions in plants: defence against predators and against certain effects of climate change, interactions with other plants, etc. (Peñuelas *et al*. 1995). They have an important influence in atmospheric balances of C (Peñuelas 2001), especially in areas with Mediterranean-type vegetation. They also show several types of interaction with greenhouse gasses and are, together with N oxides and hydrocarbons of anthropic emission, among the precursors of formation of tropospheric ozone, which is favoured by the high temperatures and irradiation typical of the Mediterranean climate. Ozone has negative oxidising effects for organisms, which are accentuated in environments with high levels of atmospheric humidity, such as coastal ones, and in turn, it stimulates the defensive emission of VOCs by the plants. The final balance of this synergy is unclear, because the emission of VOCs could be limited in conditions of water stress, and its effects would at least amplify some of the aforementioned direct impacts, and would also influence the balance of interactions among species.

The increased UV radiation associated with atmospheric changes is considered to be a less important factor in Mediterranean areas, because the flora therein is endowed with great physiological protection against over-radiation. Possible effects, however, have been indicated in relation to the chemical composition of the phytomass (Gehrke *et al*. 1995) and to edaphic micro-organisms (Caldwell *et al*. 1999).

Changes in land use, with regard both to type and intensity, are considered to be the factor with the greatest current impact upon biodiversity in general and that of Mediterranean ecosystems in particular (Sala *et al*. 2000). This circumstance, which greatly hinders the detection and interpretation of effects strictly attributable to climate change, will bring about new modifications in distributions and types of uses (Parry 1992), with tendencies towards the abandonment of agriculture and livestock farming in the territories in which climatic conditions become adverse, the displacement of these uses to new territories with more favourable climatic conditions, an increase in intensive use modalities as a way of attenuating climate changes, changes in forestry uses, crises in certain traditional land use systems, new locations of urban housing and infrastructures, etc. The distribution of uses determines other factors, such as the fragmentation of landscapes, which will condition and limit the migration possibilities of species. Furthermore, the characteristics of the fire regime are closely related to the composition of the landscape and of fuels, and therefore to land uses. The synergic effects of climate change and of changes in uses will constitute one of the main threats for biodiversity in the coming decades.

5.3.1.4. Impacts upon inter-species interactions

Apart from the aforementioned direct and indirect effects, the behaviour of species in relation to climate change will be governed by the resulting modifications in the interactions among species. Climate change will locally modify the competitive relationships among plant species. Wherever the reduction of hydric availability is moderate, warming will intensify the aerial competition among plants, which is mainly asymmetrical. Species displacement and local extinction will also modify the role of competitive relationships. In places with a predominance of aridification and other processes reducing productivity, aerial competition will become less important, giving way to subterranean competition (Tilman 1988). Species with greater tolerance or avoiding ability to stress will be favoured.

Both intensified competition and increased stress usually lead to a decrease in floristic diversity (Grime 2001). Processes favouring the co-existence of species, and therefore floristic richness, will also be subjected to changes, which are difficult to evaluate. In general terms, the disturbance regime (fires, droughts, etc.) will probably be intensified, although varying from one territory to another, so that it will foreseeable have a greater influence in some and a lesser one in others. These changes in the disturbance regime could favour the exclusion of species less tolerant to the new conditions and the subsequent spread of other better adapted ones. Species displacement will alter the separations between established niches, and there will be periods of instability while the new interactions become established. The new climatic conditions will also affect, among others, facilitation processes, although the direction of the changes appears to depend on the different situations (Pugnaire *et al*. 2001, Callaway *et al*. 2002). Goldberg *et al*. (1999) found no consistent intensification patterns of these interactions along productivity gradients.

In spite of their apparent self-sufficiency as primary producers, plants depend on many other organisms for nutrition (fungi and symbiotic bacteria), reproduction and dispersal (pollinating and dispersing animals). Furthermore, they serve as food (Harrington *et al*. 1999) and house and protect a multitude of dependent organisms. Local displacements and extinction will affect the species involved in these interactions. Of particular relevance will be the impacts upon those species that play important roles in ecosystems (keystone and engineer species), due to cascade effects upon other species.

The occurrence of different phenological responses among species with relationships of a mutualist, parasitic or competitive nature (for example, plants and pollinating insects, dispersing animals, phytofagous) could cause maladjustment in the relationships, thus altering the dynamics of the corresponding populations. Trophic asynchronies among birds, insects and plants have been detected in Europe (Visser *et al*. 1998, 2001; Chapter 6). Maladjustment in mutualist relationships will have negative effects on the species involved; these might be partially attenuated by the functional redundancy among species, which appears to be frequent in Mediterranean communities. Zoophilous and zoochorous plants will be more sensitive to this asynchronies, this sensitivity increasing with dependence on pollinators or dispersers. Available studies of Mediterranean vegetation indicate that these relationships often involve sets of species, both of plants and animals (Herrera 1995, 2001; Zamora 2000; Zamora *et al*. 2001), so that the mutual dependence is quite lax, which tallies with an environment characterised by fluctuations. Phenological maladjustment could constitute an added disadvantage for the species less tolerant to climate change, but it could also interfere with the possibilities of the species more favoured by climate to spread. We can therefore expect ecologically less complex structures, that is to say, with less interactions among species, in the new plant communities that will become established as climate change progresses.

Herbivory has both positive and negative effects on floristic diversity (Zamora *et al*. 2001). The negative ones will generally be accentuated with increasing aridity, especially for species sensitive to browsing or seedling depredation, which is the case of many woody species of the Mediterranean woodlands. In a reciprocal manner, the palatability of many species has worsened due to atmospheric CO_2 enrichment (Peñuelas and Matamala 1990, Peñuelas 2001).

Climate change will also favour the spread of parasite species to new territories, as well as the severity of the parasitism process upon individuals weakened by accentuated stress or even competition. This seems to be the role of certain parasite fungi in the oak decline (Brasier 1992, 1996; Brasier *et al*. 1993, Montoya and Mesón 1994). Hódar *et al*. (2003) documented a greater incidence of pine caterpillars in relict forests of Scots pine in Andalucia; the sensitivity of this type of pine forest to drought had been demonstrated in the Northeast of the Peninsula (Martínez-Vilalta and Piñol 2002). Increased mortality, especially among adults, could favour the creation of niches that could be occupied by other species, either local or immigrated ones, which are better adapted to the new climatic conditions.

A relevant role will be played in these interactions by the numerous plant and animal species that humans have introduced, accidentally or deliberately, away from their native habitats. The invasion processes by these exotic organisms are considered to be a component of global change as important as habitat destruction or fragmentation (Vitousek 1994, Vitousek *et al*. 1997). Exotic species modify the ecological conditions and processes (nutrient recycling, soil structure and properties, disturbance regime) of the communities into which they are introduced, and it has been shown that they can affect the genetic diversity of related native species, influence interactions among native species, cause extinction (Vitousek 1990, D'Antonio and Vitousek 1992, McNeely *et al*. 1995, Mack and D'Antonio 1999, Parker *et al*. 1999) or contribute to the homogenisation of the landscapes invaded (Dukes and Mooney 1999). Although invasion processes in Europe are severe, plants are not yet among the worst invasive organisms. It has been estimated that European flora contains around 5% of introduced species, mostly from the Eurasian continent (Lövei 1997, Stanners and Bourdeau 1998). On the Spanish Peninsula, the figures rise to almost 10% (Vilá *et al*. 2002). Excluding the exotic plants restricted to artificialized environments, 75 invasive species have been identified affecting to natural or seminatural habitats, and 45 of them show recent expansive tendencies (Dana *et al*. 2003).

Invasibility, the susceptibility of a community to invasion is a controversial theme, in which a key factor appears to lie in the existence of fluctuations in the availability of resources (Davis *et al*. 2000, Grime 2001). Disturbances, natural or artificial, but also other events that temporally increase the availability of resources, such as irrigation, fertilisation or eutrophication, initiate periods with a propensity for entry of invasive species, until the subsequent recovery of the community reduces the excess of resources. Invasive events are therefore of a clearly intermittent nature. As climate change causes population decline and local extinction, or accentuates the regime of certain disturbances, there will be periods characterised by environmental fluctuations in which the exotic species will find opportunities to spread. Sobrino *et al*. (2001) described signs of this type of spread, although it is still difficult to delimit the influence of other components of global change. Insularity is considered as an added risk related to invasive plants. This threat is particularly severe in the case of Canary Isles, with 45 species endangered or critically endangered for which competence with exotic species has been indicated as a risk for survival of some or even all of their populations (Dana *et al*. 2003).

5.3.1.5. Changes in vegetation and climate change: feedbacks

Although vegetation may appear to be a passive witness to climate changes, changes in the structure and composition of plant cover have an influence on climate, through the role they play in the radiative balances derived from the albedo, in evapotranspiration and water balances, in the production of organic matter and the composition of soil properties and in the spatial configuration and characteristics of fuels, which determine important properties of fire regimes, in emissions of VOCs, etc. Phenological changes and in particular the associated lengthening of the period of vegetative activity, will also affect determinant factors of climate change, such as carbon cycle and balances, and will also modify the water and nutrient flows of ecosystems (White *et al*. 1999), interfering, in turn, with some of the indirect effects of climate change.

We can conclude from this section that the predictable effects of climate change on plants will affect, directly or indirectly, practically all of their demographic and ecological processes: productivity, growth, chemical and genetic composition, nutrition, phenology, pollination and reproduction, dispersal, germination and recruitment, mortality and interactions with other species. These impacts will be dealt with through changes in the dynamics of the populations affected, including local migrations and extinction, which will generate changes in the composition, structure, distribution and functioning of the resulting communities. Most of the impacts indicate the structural simplification and reduced cover of the new communities, which will contain less interrelated species, with an abundance of those of great ecological amplitude, wide geographic and altitudinal distribution, tolerance to water stress, good dispersal ability, great phenotypical plasticity and genetic variability, etc. As current vegetation distribution follows biogeographic patterns associated with climatic ones, and as the projected climate change is not spatially uniform, the foreseeable impacts will be dealt with in different ways, depending on territories and vegetation types. Although the possible floristic changes will be governed by the individual responses of species, individualised predictions for the flora as a whole are beyond the reach of current scientific knowledge. An analysis is therefore provided of the projections by the Promes model, along with the consequences derived from this for each one of the main types of vegetation represented in Spain. This type of approach, although imperfect, is useful for identifying potentially significant effects in the different territories and habitats, insofar the reduction of the areas climatically appropriate for a determined type of habitat determines the magnitude of the risk of extinction of the typical species therein (Thomas *et al*. 2004).

5.3.2. Analysis of the projections by the PROMES model

In order to develop the assessment of the climate changes most significant for different types of vegetation, the projections by Promes (see Chapter 1) have been transformed to the units of the bioclimatic classification most commonly used in Spanish studies of vegetation (see 5.2.1). This classification (Rivas-Martínez 1997, Rivas-Martínez *et al*. 1999, 2002) makes use of summertime ombrothermal quotients in order to separate Mediterranean climates from Temperate ones (Fig. 5.4), an annual temperature sum (positive temperature) as a delimiting variable of the thermic belts or thermal types (Fig. 5.5), and an annual ombrothermal quotient (ombrothermal ratio) as a delimiter of the ombric belts or ombrotypes (Fig. 5.6). The results are mapped in figures 5.4-5.6 with the resolution of the 50 x 50 km cells generated by the model. The transition matrices are also shown between the units of climatic classification used in the 1961-1990 period, and the two SRES scenarios (B2 and A2) projected for the 2070-2100 period, based on demographic, socioeconomic, and technological tendencies similar to the currently predominant ones. In these matrices (Tables 5.3-5.5), each bioclimatic classification unit has been subdivided into two sub-units (upper and lower) in order to improve the resolution of the transitions.

The projection of the same model for the 1961-1990 period was taken as a reference framework for the present climate, as no other one with the same scale of geographic resolution was available. This projection, transferred to the units of the climatic classification used, reflects quite appropriately the relationships established between the vegetation and the present climate, although it exaggerates certain contrasts which ought to be taken into account in the comparisons. For example, the temperate climates are superimposed throughout the Iberian Range, as are the semiarid ombrotypes in the South. With regard to the latter, it seems that part of the lower dry ombrotype is reflected as upper semiarid by the model. To the contrary, the present area of the thermomediterranean belt is underrepresented, and perhaps also that of the thermotemperate one on the Northwestern coast.

Fig. 5.4 shows the change in the Mediterranean-Eurosiberian climatic boundary in the two scenarios. The "mediterraneisation" of the Peninsula, which is the most notable tendency, is more evident in the Northwest than in the Northeast, and it advances along three wedges: the Cantabrian coast, the Ebro valley and perhaps the northern slopes of the Pyrenees. The temperate climates are confined in the Cantabrian Range and the Pyrenees, and, although they still maintain certain continuity in scenario B2, they show clear evidence of fragmentation in A2.

The modifications in the distribution of the bioclimatic belts (Fig. 5.5) highlight the big spread of the thermomediterranean belt in the Southwest of the Peninsula and even the appearance of the inframediterranean belt, the closest current representation of which is at relatively distant latitudes in North Africa and in the Canary Isles. As a whole, the area of these warm Mediterranean climates is multiplied by six in scenario B2 and by eight in scenario A2. Furthermore, this spread over one century surpasses the maximum migration distances documented, and warm Mediterranean flora could therefore be expected not to reach the new northern distribution limits in this space of time. The spread of the thermomediterranean along the eastern coast is more moderate and restricted to the coastal area, so that, in scenario B2, it only slightly surpasses its real present limits towards the North and in the Ebro Valley. The distribution of the mesomediterranean belt, currently the most widespread, suffers a big displacement towards the North and the West of the Peninsula, but maintains a similar total area.

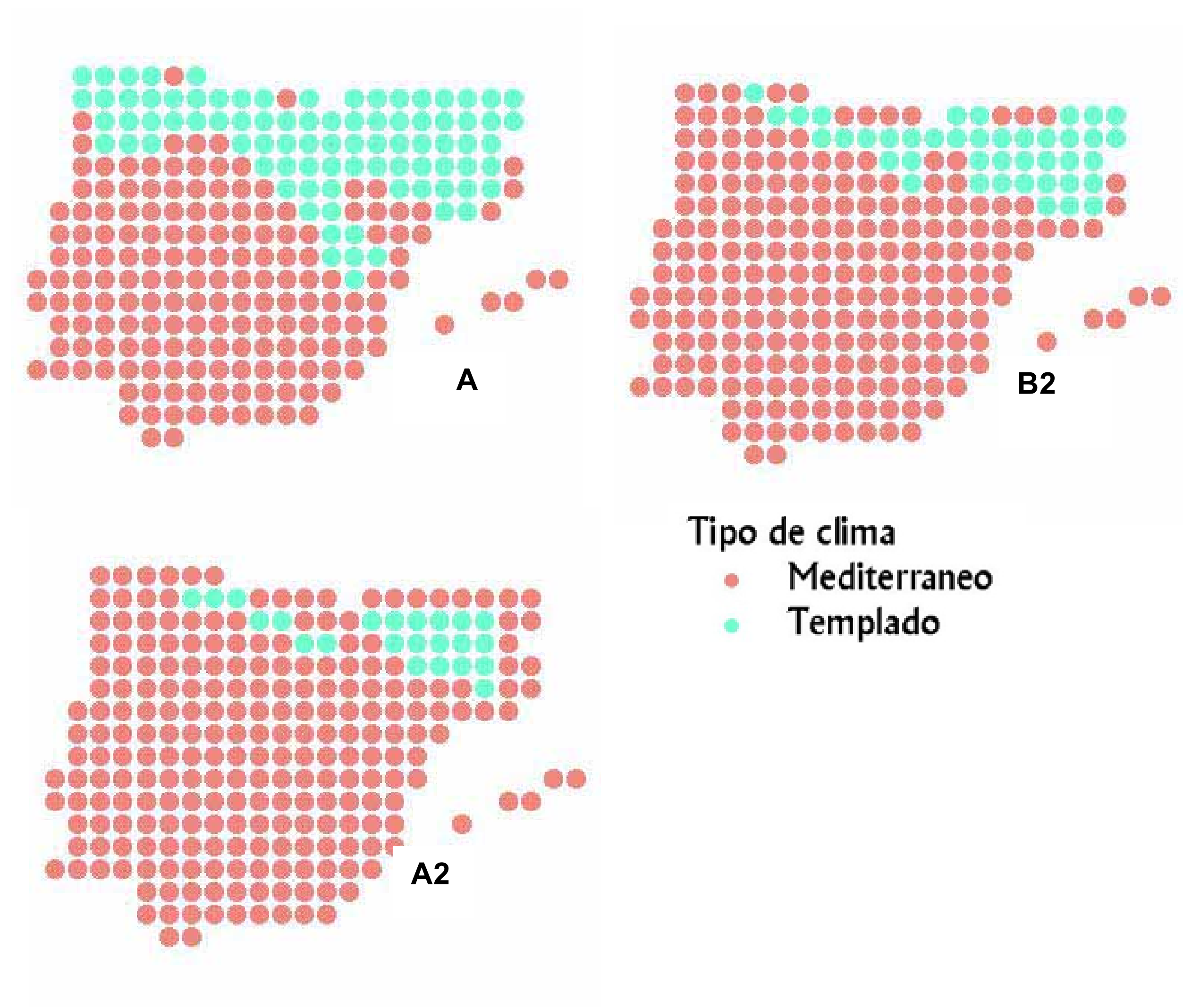

Fig. 5.4. *Changes in the distribution of Mediterranean and Temperate climates according to the projections by Promes (scenarios B2 and A2; A: present climate).*

Table 5.3. *Transition matrices (number of 50 x50 km grid cells) between Mediterranean and Temperate climates in the two scenarios.*

Scenario B2	**Med.**	**Temp.**
Mediterranean	175	
Temperate	45	41

Scenario A2	**Med.**	**Temp.**
Mediterranean	175	
Temperate	63	23

***Table 5.4.** Transition matrices between bioclimatic belts (thermotypes) in the two Promes projections (B2 and A2). The rows indicate the number of grid cells corresponding to the current thermotypes and the columns, the number corresponding to each of the projections. Two subdivisions have been considered for the main thermotypes: lower or inferior (inf.) and upper or superior (sup.).*

SCENARIO B2	IM	TMi	TMs	MMi	MMs	SMi	SMs	TT	MTi	MTs	STi	STs	OT	*Total*
Inframediterranean														*0*
Thermomediterranean inf.	3													*3*
Thermomediterranean sup.	7	4												*11*
Mesomediterranean inf.	3	33	27	2										*65*
Mesomediterranean sup.			5	42										*47*
Supramediterranean inf.				9	27									*36*
Supramediterranean sup.					6	7								*13*
Thermotemperate														*0*
Mesotemperate inf.			2	5				1						*8*
Mesotemperate sup.				7	6				9					*22*
Supratemperate inf.					10	1				15	1			*27*
Supratemperate sup.						11	3				9			*23*
Orotemperate											1	4	1	*6*
Total	*13*	*37*	*34*	*65*	*49*	*19*	*3*	*1*	*9*	*15*	*11*	*4*	*1*	*261*

SCENARIO A2	IM	TMi	TMs	MMi	MMs	SMi	SMs	TT	MTi	MTs	STi	STs	OT	*Total*
Inframediterranean														*0*
Thermomediterranean inf.	3													*3*
Thermomediterranean sup.	11													*11*
Mesomediterranean inf.	38	25	1	1										*65*
Mesomediterranean sup.		10	22	15										*47*
Supramediterranean inf.				32	4									*36*
Supramediterranean sup.					13									*13*
Thermotemperate														*0*
Mesotemperate inf.		2	2	4										*8*
Mesotemperate sup.			2	17	1			2						*22*
Supratemperate inf.				2	17				6	2				*27*
Supratemperate sup.					5	11				4	3			*23*
Orotemperate											2	4		*6*
Total	*52*	*37*	*27*	*71*	*40*	*11*	*0*	*2*	*6*	*6*	*5*	*4*	*0*	*261*

The mesotemperate or coline suffers a loss of territory as a result of the Mediterraneisation process, which is only partly compensated for by a gain in territory which is currently supratemperate. The mountain belts will experience a notable reduction. The current area of the supramediterranean is halved in B2 and reduced to a quarter in A2, and also suffers an almost complete displacement towards areas that are supratemperate at present. The supratemperate, that is to say, the Euro-siberian middle mountain, is reduced to one third in B2 and to one fifth in A2. Mediterraneisation is responsible for most (50% in B2, 65% in A2) of this reduction of the territory, the rest corresponding to warming (transformation to mesotemperate). Due to these changes, Euro-siberian mountain climates become fragmented into one nucleus in the Cantabrian region and another in the Pyrenees; the former is reduced to only one cell in scenario A2. This sharp drop in mountain thermotypes should be interpreted as a rise in altitudinal limits between belts, resulting from warming; the lesser proportion of area within the cell means that the predominant belt therein changes. On average and in accordance with the transition matrices, scenario B2 involves a displacement of almost half of the altitudinal interval of most of the belts, whereas in scenario A2, the change is equivalent to almost a whole belt, particularly in the South. It is interesting to note the more conservative thermal behaviour of the coast, and the accentuation of continentality (annual thermal amplitude) throughout the inland area of the Peninsula.

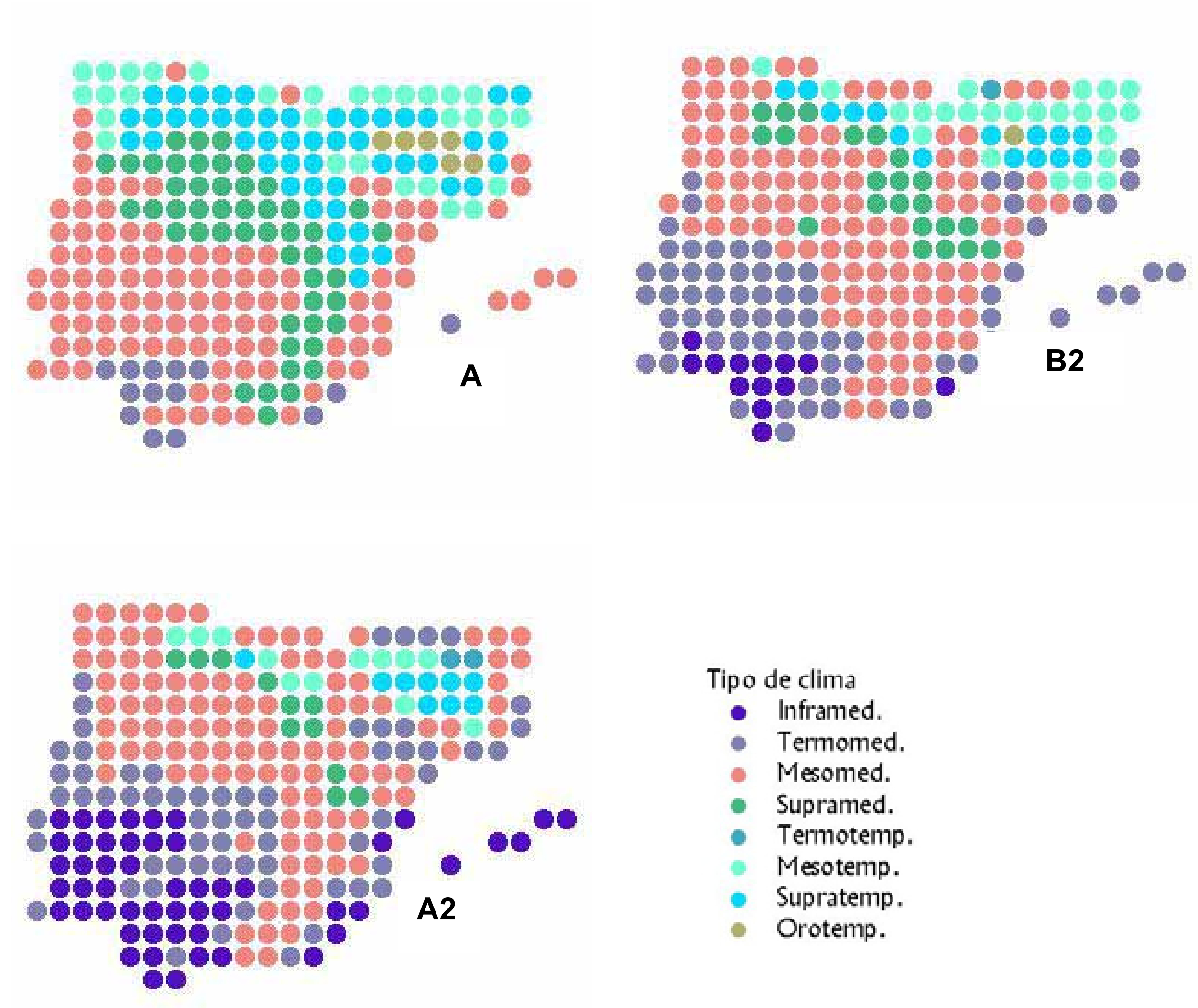

Fig. 5.5. *Changes in the distribution of the bioclimatic belts (thermotypes) by Rivas-Martínez according to projections by Promes (scenarios B2 and A2; A: present climate).*

The projection of a sharp decrease in precipitation in much of the Iberian Peninsula is one of the innovative contributions of Promes and determines that, in combination with warming, the scenarios present a considerable spread of semiarid and arid ombrotypes (Fig. 5.3.3), the latter heretofore restricted to very small enclaves on the coasts of Murcia and Almería. The semiarid ombrotypes enter well into the Ebro valley and also reach the Duero basin in scenario B2. The upper semiarid of the current projection by Promes (A) becomes lower semiarid in scenario B2, and practically the whole southern part of the Peninsula is framed within lower semiarid and arid climates in scenario A2. The appearance of the arid ombrotype in the Southwest of the Peninsula represents a considerable change, if we taken into consideration the greater stability of the semiarid-arid areas of the Southeast of the Peninsula, which only show an evident spread towards the South-eastern border of La Mancha in scenario A2.

Table 5.5. *Transition matrices between bioclimatic belts (ombrotypes) in the two Promes projections (B2 and A2). The rows indicate the number of grid cells corresponding to the current ombrotypes and the columns, the number corresponding to each of the projections. Two subdivisions have been considered for the main ombrotypes: dryer or lower, and more humid or upper.*

SCENARIO B2	A	SAi	SAs	Si	Ss	SHi	SHs	Hi	Hs	HH	*Total*
Arid	3										*3*
Lower semiarid	9	4									*13*
Upper semiarid		42	1								*43*
Lower dry		5	40	7							*52*
Upper dry			3	33	2						*38*
Lower sub-humid				9	20	1					*30*
Upper sub-humid					6	21	1				*28*
Lowe humid						7	15	9			*31*
Upper humid								17			*17*
Hyperhumid									3	3	*6*
Total	*12*	*51*	*44*	*49*	*28*	*29*	*16*	*26*	*3*	*3*	

SCENARIO A2	A	SAi	SAs	Si	Ss	SHi	SHs	Hi	Hs	HH	*Total*
Arid	3										*3*
Lower semiarid inferior	13										*13*
Upper semiarid	16	27									*43*
Lower dry		33	19								*52*
Upper dry		2	16	20							*38*
Lower sub-humid				22	8						*30*
Upper sub-humid				5	17	6					*28*
Lowe humid						17	13	1			*31*
Upper humid							9	8			*17*
Hyperhumid								2	3	1	*6*
Total	*32*	*62*	*35*	*47*	*25*	*23*	*22*	*11*	*3*	*1*	

In the North of the Peninsula, the dry ombrotypes recovers much of the area lost in the South. The sub-humid and humid ombrotypes undergo clear fragmentation processes throughout the Central and Iberian ranges in scenario B2, which are accentuated in A2. As a whole, the upper subhumid or more humid ombrotypes are reduced in area by 40% in scenario B2 and by 60% in A2. The northern third of the Peninsula continues to be dominated by sub-humid climates, with humid nuclei located in Galicia, the Cantabrian range and the Pyrenees, which even subsist in scenario A2. Rainy Mediterranean climates (sub-humid and humid) are therefore the ones that become predominant in the North at the expense of the temperate ones.
The increasing aridity in the South is more marked than in the North, and, once again, it seems that the changes in the West of the Peninsula will be more accentuated than in the East. Therefore, apart from the generalised “mediterraneisation”, the rainy Mediterranean enclaves become drastically reduced in their present locations and are displaced northwards. Contrary to what was stated in previous reports (Parry 2000), which predicted moderate impacts for Mediterranean vegetation, the currently available projections indicate big changes in the main climatic limits for vegetation, at least in the western Mediterranean.

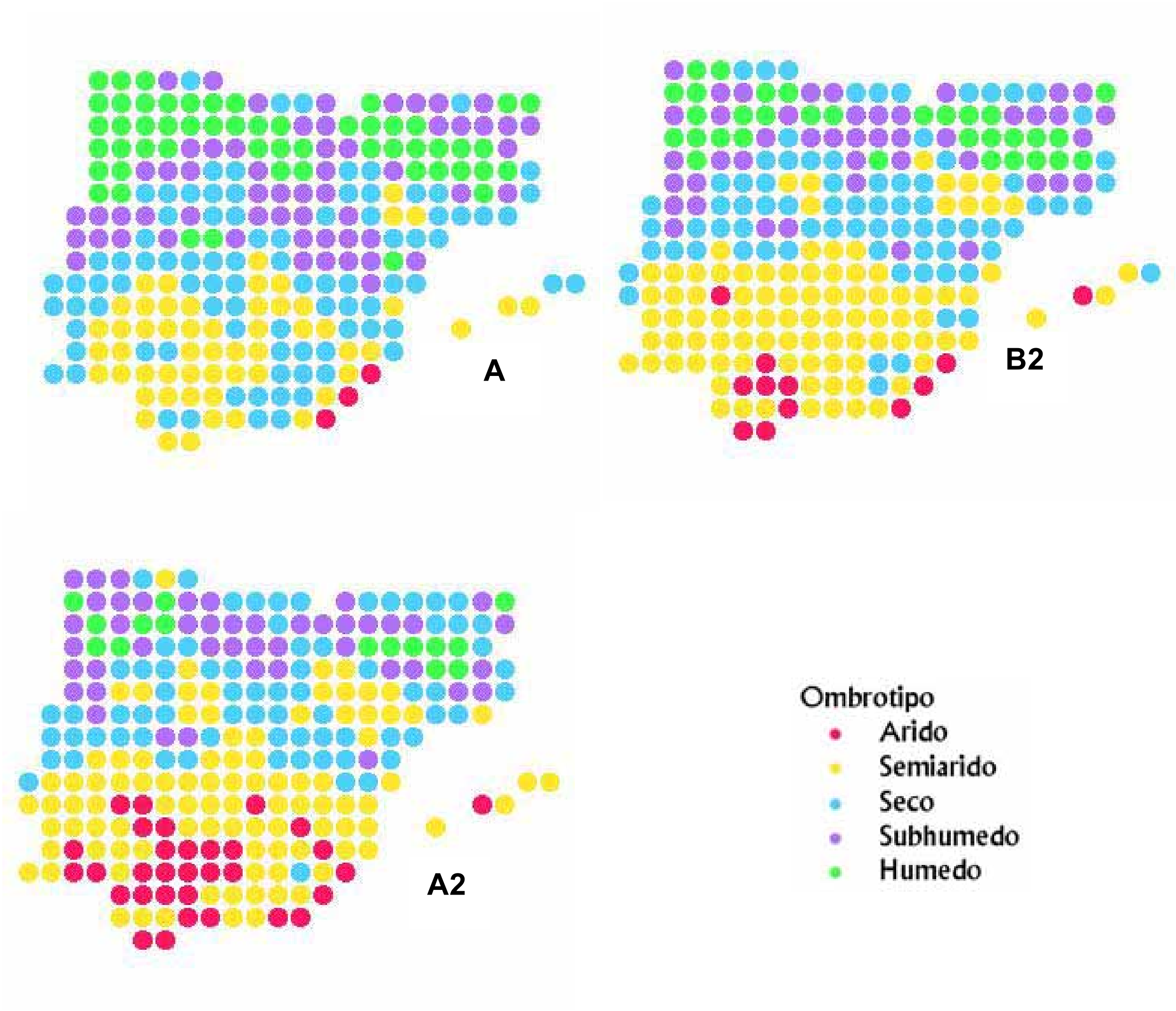

Fig. 5.6. *Changes in the distribution of the bioclimatic belts (ombrotypes) by Rivas-Martínez according to projections by Promes (scenarios B2 and A2; A: present climate).*

Regardless of their reliability, the implications of the aforementioned climate change scenarios may be very different for flora and vegetation depending on the trajectories that these changes really follow. In the case of temperatures, the projections indicate more or less linear change tendencies. In the case of precipitation, however it seems the fluctuations will be considerable, which would hinder possible movements of vegetation due to the antagonistic effects between warming and aridification. Several projections at mid term suggest in some peninsular territories that aridification could be compensated by a seasonal redistribution of rainfall (del Río 2003, del Río *et al*. 2004), which would act favouring vegetation changes opposed to those announced by Promes for the long term.

5.3.3. Analysis of impacts according to vegetation types

5.3.3.1. High mountain vegetation

High mountain habitats above the timberline comprise diverse types of herbaceous and shrub vegetation adapted to short periods of vegetative activity, intense cold, variable snow cover and soils characterised by the high erosive energy of the relief (Billings and Mooney 1968, Beniston 1994). The geographic isolation and specificity of these environments have promoted their richness in endemisms, and, in the case of Iberian mountains, in taxa at the southern limit of their distribution. It is therefore not surprising that many high mountain habitats are included in the Habitat Directive (Romao 1996, European Commission 2003).

Their close relationship with high mountain climates and cryoturbated soils means that generalised climate warming would be especially unfavourable for them. The spread of woody vegetation (bushes in the cryorotemperate and cryoromediterranean belts, trees at the lower limits and intermediate levels of the orotemperate and oromediterranean), accompanied by herbaceous flora which is currently at its optimum at lower altitudinal levels, would reduce the area available for high mountain vegetation and alter its composition, especially in relation to psychoxerophile and chionophile pastures. Although the climate change projected suggests that between half and practically all of the altitudinal interval currently assigned to the cryorotemprate and cryoromediterranean belts could be affected, it is unlikely that in one century there could be an altitudinal spread of several hundred metres of the current upper limits of woody vegetation. Estimates for the Alps indicate that increases in mean annual temperature of over 3ºC would have serious impacts, but over a period of various centuries (Körner 1995, Theurillat 1995). However, on many mountains below 2,300-2,400 m altitude, very considerable reductions and denaturalisation of mountaintop habitats are to be expected. The flora of these habitats would avail of refuges in particular types of topography: crests, snowfields, scree or abrupt and exposed slopes, depending on the ecological requirements, as can be seen at present on more modest mountains (between 1,400 and 1,800 m), where similar phenomena must have occurred following the last cold postglacial pulses. But the reduced area and the competition between woody plants and herbaceous ones from lower levels will reduce the high mountain floristic ensemble and increase the fragmentation of populations. Warming will attenuate the differentiating effects of relief and microtopography, reducing the diversity of the high mountain microhabitats. Although floristic diversity can increase locally, regional richness will decline, due to the loss of flora exclusive to these habitats. In the Pyrenees, for example, the more orophile vegetation of *Loiseleuria procumbens* or *Arctostaphylos alpina*, currently relictic, will be probably jeopardized.

The foreseeable decrease in snowfall, both in terms of precipitation in the form of snow and permanent snow cover, will determine the recession of all types of chionophile vegetation and particularly of the *Nardus stricta* swards and chionophile pastures of calcareous substrates, which will disappear from their current lower elevations in the surroundings of Cantabria and the Pyrenees. They may possibly persist at higher elevations, but in small areas within the high mountain mosaic. Furthermore, the spread of woody and herbaceous vegetation from lower elevations will be easier in soils long covered by snow, which are deep, cool and more productive. The relative proportions of xerophile and chionophile pastures will be modified in high mountain areas; the former might benefit from the aridification tendencies of the climate. The changes in the albedo caused by the decrease in snow cover will accelerate warming in the high mountain; a similar effect has been attributed to the proliferation of woody vegetation (Betts 2000). The snowfield habitat in the higher zones will suffer even more, with local extinction in the mountains more to the South (Cordillera Central, Sierra Nevada). Similar risks threaten peaty *Nardus* swards and high mountain bogs, which, apart from depending on soil water regimes, will undergo an acceleration of the mineralisation of organic matter caused by warming.

Big changes in land uses are not to be expected in high mountain areas. The profitability of many winter sports facilities will be negatively affected, although their conversion to other leisure and tourism activities could be an alternative. The exploitation of springs for production of artificial snow would alter severely soil hydrology. Livestock carrying capacity could be increased on some mountains as the availability of summer pastures at middle elevations decreases. A reversion of the predominant tendency in livestock during the last century could be used to control the proliferation of woody vegetation, but it would favour the spread of herbaceous plants coming from meadows at lower elevations.

Floristic changes in high mountain vegetation and in the altitudinal limits of certain species are among the first ones documented and attributed to the effects of climate change. Grabherr *et al*. (1994, 1995, Gottfried *et al*. 2000; Pauli *et al*. 2001) detected changes of this type in herbaceous species in the Alps throughout the last century, although with mean climbing rates of 1-4 m/decade as opposed to the 10 m/decade that might be expected for an estimated warming rate of 0.7ºC. Sanz-Elorza *et al*. (2003) indicate densification processes in scrub plants (gorse and dwarf juniper) at cryoromediterranean altitudes in the Central range for the 1957/1991 period. These rises in elevation are moderate and the influence of reduced pressure by livestock cannot be fully ruled out (Archer *et al*. 1995). A rise in the upper forest limit would probably require longer time periods (Burga 1988, Ammann 1995) and might react negatively to climatic variability, as seen in studies of *Pinus uncinata* in the central Pyrenees (Camarero and Gutiérrez 2003). Peñuelas and Boada (2003), however, detected an ascent in the upper altitudinal limit of beech forests in Montseny, evaluated by at 70 m for the last 55 years (13 m/decade), although this was not independent from the abandonment of livestock farming uses. Rises in the upper forest limit have also been detected in Scandinavia (Kullman 2001), where the signs of climate change are more notorious, in the Balkans (Meshinev *et al*. 2000) and in New Zealand (Wardle and Coleman 1992).

5.3.3.2. Forest vegetation: forests

Forests constitute the natural potential vegetation of most of Spain, with the exception of high mountain areas, the semi-arid parts of the Peninsula and the arid and desertic areas of the Canary Isles (Rivas-Martínez 1987, Blanco *et al*. 1997). The diversity of our forests at present and their diverse bioclimatic spaces mean that we can expect very varied responses to climate change.

Deciduous forests predominate in the Euro-siberian area, but there are also large areas in the Mediterranean mountains. The more ombrophile deciduous forests, such as beech, oak and fir forests, mixed forests, etc., will be negatively affected by the aridification of the climate and the accentuation of summer drought (Mediterraneisation). In some woodlands in the Pyrenees, the pre-Pyrenees, the Castilian-Cantabrian transition, the northern Iberian range and the Central range (Ayllón, Somosierra), beech forests will suffer severe recessions with regard to area which will cause them to become extinct or merely residual, as it also will with the oak forests of *Quercus petraea*. In other territories, they will experience a noteworthy retrocession. Something similar is expected for the Carpetan birch forests of *Betula celtiberica,* the oretan of *B. parvibracteata* and the ones in the sub-Betic and Sierra Nevada ranges involving *B. fontqueri*.

Other deciduous forests with bigger areas at present and less hydric requirements will suffer big losses of some of their territories, but they will have possibilities to remain in others and even to spread, at the expense of more ombrophilous forests, such as beech or oak forests. It is the case of the *Quercus robur* mixed forests of the Galicia-Cantabria regions, *Quercus pubescens* Pyrenean forests from Pyrenees, and *Q. pyrenaica* and *Q. faginea* forests. The latter are best represented in sub-humid or humid supramediterranean climates, in which they will become reduced, while its role will become more prominent in the neighbouring supratemperate territories. To the contrary, the forests of *Quercus pyrenaica* and *Q. faginea* subsp. *faginea,* as well as the Andalucia *Q. canariensis* forests and the Portuguese oak forests (Q*. faginea* subsp. *broteroi*) of the Southwest of the Iberian Peninsula, will suffer a severe crisis, with local extinction due to a lack of refuge altitudes and the impossibility of migrating northwards. The crisis will be more acute in the Southwest of the Peninsula than in the Ibero-Levantine area.

The responses of these forests negatively affected by the projected climate change are complex and will be verified at temporal scales that are surely longer than those of the projections. In those species that have the chance to spread at the expense of others, it must be kept in mind that the recession in areas affected by climate change could be quite rapid, as recurring drought, the associated plagues and other disturbances decimate the adult trees and reduce recruitment. The spread, however, will be much slower, due to the longevity of the dominant species and to the fact that several generations are needed for a tree species to significantly amplify its territory in a natural manner. It does not seem possible that the migration speeds documented in the Quaternary post-glacial periods to be reached, due to the degradation of present landscapes and to the fact that the destination habitats will, in many cases, be occupied by other species. Disturbances could accelerate the change dynamics, but the foreseeable balance indicates that the spread will not compensate for losses of territory, at least in the medium term. The forests with the best chances of persisting will be those with sufficient altitudinal or latitudinal continuity. In the forests located in territories subjected to retreat, refuges might subsist in areas with favourable topography (ravines, shaded areas, northern exposures), and topographic diversity will therefore be another important factor in the change dynamics. The retreat processes governed by disturbances could give rise to the temporary disappearance of the tree cover until new cover is generated which is in accordance with the characteristics of the climate. In these periods, many species associated with the forest environment may become jeopardized or rapidly disappear. Furthermore, the substitution of a deciduous canopy by a perennial one will lead to changes in the light regime, which will affect the rich deciduous underbrush. Peñuelas and Boada (2003) described the progressive substitution of beech forests by Holm oak forest in a relatively large altitudinal interval (700-1200 m) on the southern slopes of Montseny during the last half century. The replacement dynamics appear to be quite effective in the ecotone zones between both types of forest, and are supported by differences in the recruitment by both species and by a greater incidence of defoliation or decoloration symptoms in the beech trees situated in the retreat areas of the beech forest.

The casuistics of conifer forests are also varied. Generalised warming and aridification will cause area reductions in high mountain species, such as forests of mountain pine (*Pinus uncinata*), of Scots pine (*Pinus sylvestris*) and even of black pines (*Pinus nigra s.l.*). In certain currently rainy areas, however, such as the Pyrenees, the Scots and black pine forests could make use from the decreased water availability to gain ground from deciduous forests requiring rainfall. The lower covering of snow will cause modifications in the composition of high mountain forests; in the Pyrenees, for instance, a decrease is to be expected in forests of *Pinus uncinata* with rhododendrons in favour of pine forests with *Arctostaphylos*. The increasing incidence of plagues has already been documented in southern relictic enclaves of Scots pine (Hódar *et al.* 2003), as has been the sensitivity of these to drought in northern enclaves on the Peninsula (Martínez-Vilalta and Piñol 2002).

The behaviour of Spanish juniper woods (*Juniperus thurifera*) is more difficult to predict. Their present territories, mainly supramediterranean and inland ones, will be exposed to warming but also to decreased rainfall, which, in combination with edaphic characteristics, could constitute an obstacle for them in relation to the spread of sclerophyllous or deciduous species of *Quercus*. Furthermore, the Spanish juniper tolerates semiarid mesomediterranean climates, as can be seen in their populations in the Ebro basin and in the Southeast of La Mancha. To the contrary, they have little resistance to fire disturbances, and, indeed, their present distribution is associated with regimes of low incidence and recurrence of fires (Vázquez *et al*. 2002). Something similar can be said of *Juniperus oxycedrus* forests, currently very fragmented in abrupt enclaves in the centre and west of the Peninsula. Both types of forests must have occupied bigger areas in more arid but colder eras of the recent Pleistocene. The Arbor-vitae woods (*Tetraclinis articulata*), now relictic in the Sierra de Cartagena hills, could, however, be favoured by climate change, in view of its climatic preferences in Northwest Africa. The opposite occurs with the pinsapo (*Abies pinsapo*), an endemic fir to the mountainous regions of Malaga and Cadiz (Arista *et al*. 1997), where, in most of its current altitudinal interval, conditions will become too hot and dry for its present requirements.

The response by Mediterranean pine forests, which currently constitute most of the forested area of the Peninsula, will also be varied. We have already mentioned the foreseeable decrease in area of maritime and black pine forests, at least in some of the present enclaves, as a consequence of aridification. Furthermore, the latter will become more susceptible to fire in its present territories, as this type of disturbance leads to regenerative failure (Trabaud and Campant 1991, Escudero *et al*. 1997, 1999; Rodrigo *et al*. 2004). Maritime pine forests respond well to fire, although with big differences from one territory to another (Faraco *et al*. 1993, Pérez *et al*. 2003). The Aleppo pine (*Pinus halepensis*) could benefit, at least in the East of the Peninsula, as it resists semiarid climates relatively well, is capable of becoming established in open areas, furthermore, and its competitive capacity in relation to Holm oak increases with drought and with recurring disturbances (Zavala 1999, 2003; Zavala *et al*. 2000).

Sclerophyllous forests are exposed to diverging tendencies. The mediterraneisation of the northern third of the Peninsula will favour the spread of Holm oak and cork oak forests –above all in the Northwest- at the expense of other deciduous forests. Peñuelas and Boada (2003) documented a process of this nature at the mid-mountain level in Catalonia. The spread should be more rapid in the lowlands, although the higher degree of deforestation would counteract this. The fragmented enclaves of sclerophyllous forests on the coast and in inland valleys of Galicia, on the coast and in the mountains in the Basque Country and Cantabria and on the southern slopes of the Pyrenees, will constitute efficient nuclei for this spread. In the Mediterranean region, however, although aridification will favour altitudinal rises of sclerophyllous vegetation also at the expense of mainly deciduous forests, the potential losses of territory will be greater, due to the spread of semiarid and arid climates, especially in the South. The sensitivity of sclerophyllous forests has been confirmed in recent drought episodes, due to their poor hydric efficiency in extreme conditions and to their slow subsequent recovery, and these effects are accentuated on sun-facing slopes and in well-drained soils or soils with little retention capacity (Peñuelas *et al*. 2000, 2001; Martínez-Vilalta *et al*. 2002a). The accentuation of symptoms such as the oak decline in holm and cork oaks, currently widespread in the Southwest (Montoya and López Arias 1997), will be one of the mechanisms intervening in the retreat of sclerophyllous forests (Brasier 1992, 1996; Brasier and Scott 1994, Montoya and Mesón 1994). Increasing aridity will have a great impact on the main nucleus of Iberian *dehesas,* an agro-forestry system of great biodiversity in which the regeneration of the trees is problematic because of interactions with the livestock farming use (Pulido *et al*. 2001). Both the structure of the *dehesas,* including the maintenance of the trees, and the livestock farming use itself, will be negatively affected by the projected climate change.

The territory that might be lost by the holm oak forests in the South will be compensated for to a great extent by territories gained in the North, to which they have easy access due to the widespread distribution of this tree on the Peninsula. The recession of the cork oak will be more irreversible, due to its greater hydric requirements, in the South and especially in the Southwest, (western Andalucia, Sierra Morena, Extremadura and Montes de Toledo), where high-altitude refuges are scarce and limited in extent.

5.3.3.3. Shrub vegetation

Tall shrublands and scrub involve extraordinarily varied types of vegetation in Spain, and contain a notable floristic diversity. Indeed, in spite of their relative structural simplicity, their floristic composition responds with high turnover rates to climatic, edaphic and geographic gradients. As with forests, most types of shrubland vegetation are included in the Habitats Directive, and some of these have been given priority interest.

The responses by shrubland vegetation to climate change will depend in each territory on the predominant direction of the antagonistic change tendencies. The increased productivity promoted by warming and reinforced by growing CO_2 concentrations will favour the tree development and the successional displacement of shrubland communities, but also colonisation by shrublands from pastures or abandoned croplands, as has been occurring in the last few decades. To the contrary, aridification will favour the spread of shrubby structures, which are simpler and have less water requirements than forests. The intensification of certain disturbances such as fire, the abandonment of agricultural and livestock farming uses on land that suffers from decreased productivity as a result of climate change, and the collapse of certain forests affected by drought, will be parallel processes favouring the spread of shrublands, which, in any case, will undergo big readjustment processes in their floristic composition and distribution.

Deciduous shrublands comprise different types of deciduous thickets and forest-fringes (with perennial species in some cases, such as boxwood forests of *Buxus sempervirens*), which are widespread as a pre-forest stage in many Euro-Siberian forests, in mountainous areas of the Mediterranean and along river valleys. As a result of their hydric requirements, they could be expected to suffer recessions in most of their present distribution areas, which could be particularly acute in their southernmost representations in Andalusian ranges.

The current distribution of sclerophyllous shrublands mainly comprises the thermo and mesomediterranean belts, as well as some enclaves isolated in southern Euro-Siberian territories, which will act as expanding nuclei as mediterraneisation becomes accentuated. Thus, climate warming and aridification will promote their spread, both in altitude and towards more northern latitudes. Aridification will also favour the spread of formations typical of semiarid and arid climates (kermes oak garrigues, thorn brushes in the Murcia and Almeria regions, etc.), which will at least increase their potential distribution areas. Their possible spreads will not be homogeneous because resistance to drought differs among species, both in adult individuals (Martínez-Vilalta *et al*. 2002, Ogaya *et al*. 2003), and in seedlings (Ogaya *et al*. 2003, Vilagrosa *et al*. 2003). Indeed, some types of sclerophyllous shrublands with high hydric requirements could be expected to suffer losses of territory, especially in the South and Southwest of the Peninsula: tree strawberry, (*Arbutus unedo,* see Martínez-Vilalta *et al*. 2002, Ogaya *et al*. 2003), heathlands of *Erica arborea, Quercus lusitanica* scrub, etc. To the contrary, these same types, or other similar ones (laurel groves, for example), will increase their territory in the mediterraneised areas in the northern third of the Peninsula.

Whereas sclerophyllous shrublands are dominated by the so-called pre-Mediterranean element, mostly consisting of resprouting species, with root systems that are relatively deep, long-lived, zoochorous and demanding with regard to germination and establishment conditions, in the remaining types of Mediterranean shrublands, there is a predominance of shrubs and scrub which were more recently differentiated from the evolutive point of view, smaller and/or less long-lived, with shallower roots, often deprived of the capacity to resprout, with non-specialised or passive dispersal and diaspores that germinate easily in clearings created by disturbances (Herrera 1992, 2001). Part of this flora also presents flexible leaf architectures, including the capacity to lose some of the foliage during periods of greater drought (Valladares 2001). Although adult individuals of certain species show vulnerability to drought, particularly due to their shallow rooting systems, populations are capable of rapid recovery through germination (Peñuelas *et al*. 2001). Responses of this nature are, however, closely dependent upon climatic fluctuations (Quintana *et al*. 2004). The flora of these shrublands therefore present some of the most typical symptoms of adaptation to drought and to other characteristics of Mediterranean environments, and increasing aridity of the climate can therefore generally be expected to favour their spread. However, the relationships between the different types of shrublands and climate are very variable, and as a result, so are their responses to the projected change.

Among silicicolous shrublands, the more ombrophilous types will suffer loss of area and retreat at their current distribution limits, although probably in more moderate degrees than other, more sensitive formations. This is the case of heaths (“jaral-brezales”) of Atlantic and Iberian-Atlantic area, which are currently distributed throughout sub-humid or rainier climates. This retreat will be more accentuated in the Southwestern quadrant: Cádiz sierras, Sierra Morena, Montes de Toledo and Montes de Extremadura. Further north, in the Montes de León and the Iberian and Central ranges, and on the coasts of the Basque Country and of Cantabria, the reduction will be less drastic but with changes in floristic composition caused by mediterraneisation. Brañas or peaty heaths, given priority in the Habitat Directive, will be most severely affected and serious local extinction processes can be expected. Similar tendencies can be expected in gorse shrublands, especially in the more ombrophilous types occupying large areas in supramediterranean and supratemperate belts. Broom fields (*Retama sphaerocarpa*), however, will have possibilities to spread, due to the considerable expansion of the thermo- and mesomediterranean belts and to their tolerance to drought.

The recessions suffered by other more ombrophilous silicicolous shrublands will favour *Cistus*-shrublands (“jarales”), which will also be favoured by possible regional intensification of the fire regime. Within these, the more thermophile types will show a notable increase, particularly the types of *Cistus ladanifer* and other *Cistus* species capable of losing leaves in the dry season (*C. monspeliensis, C. salviifolius*, etc.), to the detriment of the relatively more mesophytic species such as *Cistus populifolius* o *C. laurifolius*.

Shrublands typical of particular lithologies, such as ultrabasic rocks (peridotite, serpentine), dolomites or gypsum, contain a high proportion of endemisms associated with this kind of substrates, which are selective for flora, and these will probably subsist therein with minor adjustments, considering that they have resisted, *in situ* preceding climate changes of greater magnitude. Their tolerance to stress induced by the unfavourable chemical composition of the soils they inhabit, and the low level of competition that characterises these environments, will be an advantage in the event of increased aridity. Nevertheless, monitoring of the future evolution of these habitats is advisable because the combination of the projected warming and aridification to which they will be exposed might be unprecedented in certain enclaves. In the case of the Iberian gypsum steppes, given priority in the Habitat Directive, increasing aridity could spread to gypsum outcrops in the Pyrenees and the North of the Iberian range, the present climate of which is too rainy for any manifestation of the selective effect of this kind of substrate on plants.

Shrublands typical of calcareous soils (rosemary, sage, lavender, gorse, thyme, etc), very widespread in central and eastern Spain, will undergo an advance in general terms. Floristically, they are richer than their silicicolous homologues, and contain more plants adapted to xericity. Within these, the more xeric types, currently dominant in the semiarid Southeast, will be more favoured and could spread to the inner La Mancha, South of Valencia, the Baza basin and eastern Andalucia. The more thermophilous types, now mainly restricted to coastal regions, will, spread in altitude and inland, although these spreads will filter only the elements that are less dependent on oceanity and will be moderated by the barrier effect of the coastal mountain ranges. The meseta types will not undergo big changes, except for peripheral reductions and altitudinal rises at the expense of the mid- and high mountain types. In the Ebro valley, the “romerales” (rosemary scrub) of the basin could spread at the expense of the peripheral types (Gavilán 2003). Mid- and high mountain shrublands, rich in stenochorous endemisms and cushion plants, will suffer a reduction in climatic space, although the displacement of these by more thermophilous shrubland components will be slow and limited. However, the foreseeable warming in these areas will increase productivity and could facilitate more effective displacement of shrublands by trees and tall shrub vegetation. This problem will be more marked in the Betic and sub-Betic ranges, subjected to greater warming and clearly richer in endemisms with little dispersal capacity, than in the Iberian range and in the coastal mountains of the East coast, which offer greater possibilities for migration and which will not suffer such a marked reduction in the mid- and high mountain areas.

Changes in shrubland types and areas involve other important relationships with climate change. Mediterranean shrublands release considerable amounts of VOCs into the atmosphere. Likewise, it is characteristic of many types of Mediterranean shrubland to rapidly accumulate necromass, which favours the risk of ignition and above all the spread of fires (Moreno *et al*. 1998).

5.3.3.4. Herbaceous vegetation (meadows and pastures)

Herbaceous plants constitute around four fifths of the total amount of vascular flora species in Spain. In the temperate climates in the northern third of the Peninsula, the herbaceous flora is dominated by perennial plants, and in the Mediterranean climates annual species dominate, their life cycle enabling them to avoid summer drought while resisting disturbances. Although the greater abundance and richness of herbaceous flora is found in the communities in which woody cover is lacking or reduced, and especially in those shaped by practices associated with grazing, large contingents of herbaceous flora are associated with forest and pre-forest environments, and to other large types of habitat mentioned in this section, and their responses to climate change will depend, to a greater or lesser extent, on the aforementioned tendencies of each of these habitats. The predictions for flora and vegetation in relation to climate change are varied, and will closely depend on what happens with land uses, and in particular with livestock farming, which is the one that has the greatest control over woody plants and which favours the development of different types of pastures.

The most noteworthy change tendencies for grassland vegetation will be the following ones. A general reduction of mesophile and hygrophile meadows can be expected, including mid-mountain *Nardus* swards and many forb mountain communities, dependent both on hydric availability and on the abundance of organic matter. This reduction will be moderate in the territories with temperate climates and greater in Mediterranean mountains. The representations of certain particular types at the ends of their area, such as mown meadows in the Iberian and Central ranges, might be almost completely substituted by meadows more tolerant to summer scorching, such as “ballicares” (*Agrostis castellana*), “fenalares” (*Brachypodium phoenicoides*), “gramales” (*Cynodon dactylon*), “juncales churreros” (*Scirpus holoschoenus*), etc.

To the contrary, different types of grassy steppes will gain ground, both in Euro-Siberian and Mediterranean mountains and in the Mediterranean areas most affected by aridification. Therein, there could be a spread of “espartales” (*Stipa tenacissima*), “albardinares” (*Lygeum spartum*), “cerverales” (*Brachypodium retusum*), “lastonares” (*Stipa spp., Helictotrichon spp.*), “berceales” (*Stipa gigantea*), etc. These pastures are quite tolerant to fire disturbance and habitually contain great richness and abundance of therophytes. However, certain steppes requiring relatively rainy climates, like the “cerrillares” of *Festuca elegans* in Ibero-Atlantic Mediterranean mountains, will suffer reductions of potential area and might even disappear from their present Oretan, Sierra Morena and Sierra Nevada refuges. We might also expect a recession, at least in part of their present territory, of different psycroxerophile Mediterranean pastures, currently abundant in the Betic ranges, and clearly associated with climates that promote processes of soil cryoturbation. In this case, the recession would be governed by competitive displacement by other types of vegetation favoured by climate warming, more than by aridification.

The vegetation typical of more anthropised habitats (ruderal and weed communities) will be displaced, but extinction is not to be expected, given the large climatic space typical of most of the species involved. To the contrary, in an unstable environment in which disturbances and gaps in the vegetation cover become more common, these species can be expected to have greater possibilities of spreading.

In short, the balance of the climate change projected will generally be favourable for herbaceous vegetation, although there will be important conditioning factors derived from possible changes in land uses. Climate change will generally favour xerophytic types of vegetation, annual species and, in many cases, the relatively opportunist ones, with great climatic (and therefore geographic) amplitude and agile dispersal mechanisms. Due to the short generation cycle of most species, and the facility for anemochorous and zoochorous dispersal of many of these, the changes could be relatively rapid, although the response to climate change will be more resistant in relation to water availability than to temperature regime. It has been speculated that the positive response by C_4 plants, more demanding with regard to temperature and light requirements, and with more efficient transpiration, will be more marked than that of C_3 plants, although the carboxylation capacity of these will be favoured by a CO_2 enriched atmosphere.

5.3.3.5. Rock and scree vegetation

All the vegetation typical of fissures in rocks, stony ground and scree comprises a highly specialised flora with a large amount of endemisms. Practically all these types are included in the Habitat Directive. The peculiar conditions of these plant environments combine soils with little capacity for hydric retention and poor in nutrients, with particular disturbance regimes associated with periodic earth slides or with the mobility of substrates, and they determine very open pant structures with little competition for light. The tolerance to stress of rock flora includes the capacity to resist long periods of physiological cessation or attenuation, and to concentrate activity in the short and often irregular favourable periods. Thus, this type of adverse habitat is among those less directly vulnerable to the projected climate change (Theurillat 1995).

The harshness of winter, however, is another adverse factor for these plants, and evident altitudinal zoning can be observed in their communities. Under circumstances of climate warming, the higher-altitude species (oro-cryorotemperate and oro-cryoromediterranean) could therefore be affected by the immigration of species typical of lower elevations. In any case, this process would be very slow, given the high staying capacity of this type of vegetation, as can be seen in the presence in low-altitude rocky habitats of species whose optimum elevation is at higher altitudes, reminiscent of previous cold periods.

Epiphytic vascular vegetation has certain floristic relationships with rock vegetation. It is poorly represented at our latitudes, mainly by ferns and mosses. Its dependence upon climates with high atmospheric humidity and rainfall seems to indicate a decrease in its optimum territory, with recessions towards coastal oceanic areas.

5.3.3.6. Coastal vegetation (dunes, beaches, cliffs and salt marshes)

The vegetation dealt with in this section comprises different types of habitats conditioned by coastal geomorphology and the influence of the salt spray. They are well represented in the Habitat Directive, and many of them have been given priority status due to the clear retreat of coastal ecosystems caused by the age old concentration of the human population in these areas, and to the addition, in recent times, of housing and the construction of infrastructures associated with tourism.

Climate changes should have quite moderate direct effects on coastal habitats, because the warming process will surely be gentler on the coast, and aridificaiton will be partly compensated for by the high level of atmospheric humidity caused by the vicinity of the sea. The foreseeable rise in sea level, however, could greatly reduce the areas occupied by these habitats, and there could be other changes in the geomorphologic processes that maintain dune systems and marshlands and coastal pools. Housing and infrastructures will make it difficult for these systems to gradually retreat from the advance of the sea. This restriction will be even more serious in areas like Galicia and especially Cantabria, where in certain areas, the dune and post-dune zones have been occupied for quite some time (Basque Country) or will be occupied quite soon (Cantabria). Mediterranean coasts are also affected by these processes, which contribute to fragmenting coastal ecosystems and hinder possible migration routes. The current locations of coastal wetlands will be affected by increased salinity, which will profoundly alter the composition of the mosaic of communities in these systems; in extreme cases, the sea could directly invade them. Dune vegetation and in particular woody plants, given priority in the Habitat Directive, are also among those vulnerable to these processes. In this sense, vegetation living on cliffs might prove to be the most resistant to changes.

Some psammophilous herbaceous and shrubland communities have interesting representations in inland sandy areas. As with other types of vegetation associated with unfavourable soils, the impacts to be expected are moderate, although, as these representations are very scant, any tendency towards population decrease would give rise to quite rapid extinction processes. In the case of brine basins, increased temperatures accompanied by decreased rainfall, or wintertime concentration of this, would favour their advance, especially in the Southeast of the Peninsula, the La Mancha plateau, the Ebro basin and the Duero basin.

5.3.3.7. Island vegetation

There has been speculation over whether the impacts of climate change will be greater on the islands, due to the fact that the flora (and fauna) typically present, which has become impoverished, with interactions among more fragile species and lower rates of genetic diversity of species, both endemic and non-endemic (Frankham 1997). However, at least on the smaller islands, the tempering and humidifying effect of the sea could attenuate climate change tendencies. The projections by Promes (Fig. 5.5-5.6) for the British Isles show the effects both of warming and of reduced hydric availability, although somewhat more moderate than in the East of the Peninsula. Thus, the foreseeable impacts for this archipelago will be similar to those that have been dealt with for the habitats represented therein, with the exception that there will be a higher proportion of coastal refuges. The most vulnerable points appear to be mountain vegetation in Majorca and increased aridity in Menorca.

The resolution of the projections of the Promes model for the Canarian archipelago are insufficient due to the dimensions of the islands with regard to the grids, and to the difficulty involved in interpreting the changes in the varied pluviometry of the bigger islands. The western isles will be more affected by warming, but as a whole this will be more moderate than in the mainland and has been evaluated in less than half of a bioclimatic belt for the scenario B2 and just over one half for A2. The reduction of rainfall will imply a moderate spread of the arid and semi-arid ombrotypes currently dominant in the lower altitudes of the isles. The conical topography of the isles will determine the decrease in area of the different ombrotypes and thermotypes to progressively increase in those at greater altitude. According to the peculiar climatic and altitudinal zonation of the Canarian vegetation (Rivas-Martínez *et al*. 1993, Del Arco *et al*. 2002, Reyes-Betancort *et al*. 2001, Rodríguez Delgado *et al*. 2004), it is foreseeable an expansion of the inframediterranean arid and semi-arid vegetation types -“tabaibales” (*Euphorbia balsamifera)* and “cardonales” (*Euphorbia canariensis*)-, whose more pioneer and dynamic species could play the role of vanguard: “tabaibas amargas” (*Euphorbia lamarckii, E. regis-jubae, E. berthelotii*), “aulagas” (*Launaea arborescens*), “salados” (*Schizogyne sericea*), “vinagreras” (*Rumex lunaria*), “cerrillos” (*Hyparrhenia sinaica*), “panasco” (*Cenchrus ciliaris*), and even invasive species like the "rabogato" (*Pennisetum setaceum*). On the contrary, the thermo-sclerophyllous woodlands with Canarian junipers (*Juniperus canariensis*), Canarian olives (*Olea cerasiformis*), "almácigos" and "lentiscos" (*Pistacia atlantica, P. lentiscus*), whose remnants are strongly affected by urban and agricultural land uses, will be negatively affected by aridification and will not get much chance to reach refuges at higher altitudes. Concerning the laurel forests or "monteverde", dependent upon the mist swept by trade winds, a reduction in area could be expected due to the warming of the ocean air masses and the lowering of the upper subsidence layer of warm air. The shrublands with *Hypericum canariense* and *Rhamnus crenulata* and the "fayal-brezal" of *Myrica faya* and *Erica arborea* could benefit from the retreat of laurel forests, whose persistence in the summits of some eastern isles would be problematical. The lowering of the mist-bound would favour to the Canarian pine forests (*Pinus canariensis*) and their associated broom shrublands. Negative impacts on riverine vegetation, and in particular "sauzales" (*Salix canariensis)* and palm groves (*Phoenix canariensis)*, are also foreseeable. These vegetation types are nowadays very affected by water extraction practices. Coastal habitats are also decimated by touristic infrastructures and will suffer for the remodelling of the coastline associated to the rise in sea level.

5.4. MOST VULNERABLE AREAS

The previous section highlights the fact that practically all Spain's habitats and territories will undergo relevant impacts as a consequence of the projected climate change. If we consider that the processes induced by climate change will involve pressure that will exceed the plasticity and acclimatisation capacity of many species, that the evolutionary responses are unfeasible in the short term in which the changes will occur, and that the efficiency of species migration as a mechanism of persistence will not be sufficient to compensate for local extinction, the only conclusion is that climate change will determine considerable losses of floristic diversity, added to those that are now being caused by other components of global change. This section highlights the groups of habitats and territories the plant diversity of which could be most rapidly or intensely affected, in accordance with what has heretofore been described.

High mountain

The decrease in the space climatically suitable for the flora typical of many high mountain habitats will cause reductions in their floristic ensembles, particularly relevant because of the high endemicity rate that characterises them. The risks are greater in those mountains that are not excessively high, because the altitudinal interval currently occupied by typically high mountain habitats is smaller. For the same reason, and because of the differential tendencies of the warming projected, the problems will be more serious in southern mountains than in northern ones, and more in Cantabrian Mountains than in the Pyrenees.

Mid-mountain mesophytic habitats

Most supramediterranean and supratemperate mesophytic habitats will also be subjected to the pressure of altitudinal displacement, although in this case, they will avail of higher elevations to spread to, at least in the main mountain ranges. Once again, the main risk for these ecosystems is found in the more modest mountains, such as Sierra Morena, Montes de Toledo and many foothills of other orographic systems and of the southern mountainous regions. While altitudinal displacement is an alternative for subsistence for the flora of these habitats, latitudinal migration will be very problematic due to the transversal orientation of most of the mountain ranges and to the fragmentation and alteration of the intermediate lowlands. Reduction in area and the jeopardization and local extinction of floristic elements therefore constitute foreseeable impacts. This situation is aggravated by the fact that these habitats are characterised by containing taxa at their southern distribution limit that make a substantial contribution to territorial floristic rarity (Fernández-González 1999). The recession of these mesophytic mountain habitats in the South of the Peninsula will also involve a decrease in the abundance of certain woody species with fleshy fruits, with possible repercussions for their dispersing animals. The recession and consequent impoverishment of mesophytic flora in mountain ranges will reduce one of the components of their current floristic richness; to the contrary, they will serve as refuges for the flora of habitats that are now spread to piedmonts and which are sensitive to aridification. Lastly, changes in vegetation in mid- and high mountain areas could involve serious additional risks if the local collapses of certain populations cause temporal decreases in cover, due to the intense erosive energy characterising mountain reliefs.

Warm mesophytic habitats

All Mediterranean vegetation rich in deciduous and lauroid elements associated with rainy climates in winter and spring will be subjected to opposed pressures in the North and the South of the Peninsula. In the North, the accentuation of summer drought will favour their spread from the more or less relictic enclaves they currently occupy, although this advance will be strictly conditioned by the degradation and fragmentation of the territory, forestry uses, competition with invasive species and the extremely high incidence of deliberate fires in some areas. In the South and above all in the Southwest, the lengthening of the summer drought period, combined with an insufficient soil water recharge in wintertime, will be a disadvantage and evidence exists of the sensitivity of Mediterranean deciduous and lauroid flora to the latest drought episodes. The distances are too great for the natural migratory processes of flora in the southernmost habitats. Impoverishment of the warm Mediterranean and mesophytic ensemble can therefore be expected in the South and Southwest of the peninsula. Similar comments apply to the Canarian laurel forest or “monteverde”. Invasive species will also be an important pressure for island communities.

Mediterranean forests and southern dehesas

Large areas in the South of the Peninsula currently occupied by forest will experience a considerable reduction of water availability, which will even fall below the requirements of the least demanding forests. The effects of chronic droughts in these territories have been appreciated in the last few decades. The crisis could be even more acute in the case of *dehesas*, where the problem of tree regeneration will be exacerbated by aridification, a situation that will also question the viability of its traditional agricultural and livestock farming uses.

In the South and above all in the Southwest of the Peninsula, climate change projections indicate the appearance of new types of climate, such as the inframediterranean or the continentalised versions of the thermomediterranean, and of combinations of substrates and climate types heretofore unheard of in Iberian vegetation, such as semiarid and arid ones on siliceous substrates. These new conditions will have a selective effect on the present flora, which will be partially excluded due to intolerance. As the immigration of flora adapted to these situations is unlikely, a “voiding” phenomenon may occur in regional floristic richness, along with impoverishment of communities. In such circumstances, invasibility by exotic species would be exacerbated, and these would include the cactus family and other xerophytic elements, such as certain acacias, which would find space to spread.

Coastal habitats

We have already mentioned the particular risks affecting certain coastal systems, like dunes and coastal pools, which have been accentuated by the long history of human occupation of the coast and the intensification of certain uses in the last few decades. During previous climate changes, the coasts have played an important role as refuges, and they could also play this role at present because the degree of warming is lower and the impact of aridification will be partially compensated for by the greater atmospheric humidity. To the contrary, ozone toxicity is potentially greater in coastal environments. The interactions between climate change and land-use changes will therefore be especially decisive in the conservation of coastal habitats.

5.5. MAIN ADAPTATION OPTIONS

Due to their magnitude and scope, the impacts of climate change upon plant diversity will be difficult to attenuate through the application of local measures. We will now enumerate some of the options to be considered in this respect, encompassed within the framework of the corresponding sectorial policies.

Review of the network of protected areas and of conservation policy

The present network of protected areas, including those proposed for the integration of the European network Red Natura 2000, encompasses a considerable area, although this is mainly concentrated in mountain areas and has big gaps in the intermediate plains and piedmont areas. The conservation of mid- and high mountain areas is a recommendable measure for dealing with the impacts of climate change, as it would favour the altitudinal displacements of flora. However, it is also recommendable to review the delimitation of the protected areas in order to ensure that these cover complete altitudinal intervals, up to the summit lines, particularly in mountains of moderate altitude where the upper vegetation belts have narrow elevation ranges. Furthermore, in these circumstances, the continuous and extensive representation of natural and semi-natural habitats is of special importance, especially if they are located along a broad altitudinal interval, because they will have greater possibilities for conservation, at least in part of the territory. Attention should be paid on the conservation of corridors and the connectivity between protected areas that are too far from each other for the average dispersal thresholds of plant species. In situations of warming and aridity, northern slopes and shaded areas will play an important role as refuges, and will therefore require special attention with regard to conservation. In relation to lowlands, forest habitats should be better preserved, as these will play an important role as nuclei of re-colonisation or as milestones in migratory processes. Mixed forests, with a multi-specific tree layer, will have better chances of conserving their forest structure throughout future climate changes.

With regard to other actions, an effort should be made to harmonise current figures relating to protected natural areas, which are excessively numerous (Gómez-Limón 2000), especially in relation to management, given that conservation of biodiversity will become an increasing trans-border problem. The implementation of the Natura 2000 network of protected areas could constitute an opportunity for advance in this sense. The generalisation of procedures of adaptative management of protected areas (see subsequent section 10) will constitute another vital requirement for the follow-up of the effects of climate change.

As a consequence of climate change, species protection will be subjected to a long readjustment process, which will require monitoring of threatened populations and periodic reviews of red lists and protected species lists. As species with narrower geographic distribution ranges, altitudinal intervals and smaller population sizes presumably have lower levels of phenotypical plasticity and genetic diversity, they are also the main candidates for jeopardization or extinction in situations of abrupt environmental changes. Within the conservation framework, the detection of serious population decline in species that are not threatened at present will require special attention. The regional governments should take on the main contribution to this work.

Supporting *ex situ* conservation techniques could be crucial for the threatened flora. The conclusions of the Red Book (Moreno Saiz *et al*. 2003) revealed that barely 40% of the more endangered species are currently represented by at least one of their populations in germplasm collections.

Ecological restoration and climate change

Ecological restoration should incorporate criteria for the prevention of the effects of climate change. The use of exotic species in revegetation actions should be strictly regulated; indeed, among future restoration measures we can expect the more frequent use of those aimed at eradicating invasive species. Furthermore, restoration of plant cover should consider species tolerant to climate change tendencies and the prevention of generalised failing episodes in unfavourable years.

Review of forestry policy

As in the case of restoration, we should avoid reforestation practices involving species or seedling sources that are intolerant to climate change or to the associated risks of plagues and fires. Mixed plantations are recommendable, in order to prevent failures which are to be expected in climatologically adverse years, the frequency of which can be expected to increase. Criteria based on productivity should be abandoned in many parts of Spain, in favour of ones related to the fight against erosion, post-fire regeneration and the conservation of biodiversity. The use of shrub species in reforestation should become more frequent, for the same reasons and because of the role they play in facilitating the regeneration of Mediterranean woody species (Vallejo *et al*. 2003). Aridification will promote the abandonment of unproductive agricultural land, in which the natural dynamics of secondary succession might be very slow under the new climate conditions; reforestation of these areas with species tolerant to drought and elastic with regard to fires, will be necessary in certain situations in order to avoid degradation tendencies.

Forest management techniques ought to be adapted to a framework in which the risk of erosion, fires, loss of edaphic organic matter and deficient regeneration of forest cover will be critical. Forestry treatments should pay particular attention to enclaves that can play a role as refuges or migratory stages in the displacement of flora, as well as in general to the floristic diversity of the understorey. As we learn more about the processes of vegetation displacement, through techniques of selective extraction and even planned reforestation, we will be more capable of implementing the replacement of forests. A suitable selection of the species to be used in afforestations, in particular those carried out under the CAP frame of subsidies, could contribute to mitigate the migratory constraints of many woody plants, above all in territories affected by aridification and land abandonment. In many Mediterranean types of woodland, there will also be a need for forestry treatments aimed at improving stand structure in order to favour its hydric efficiency (see Chapter 9).

Regulation of livestock farming and hunting uses in forest systems

Excessive pressure by livestock in forests and shrublands subjected to intense hydric stress can accelerate the recession of these due to insufficient natural regeneration and to the damage inflicted upon adult individuals through browsing. The regulation of carrying capacities is important in the areas of Mediterranean woodlands which are still well-conserved and used for hunting, as these have shown recent tendencies towards intensification. In the territories most affected by aridification, however, decreased plant productivity will lead to the economic collapse of extensive livestock farming, which will give rise to the impoverishment of herbaceous flora. The possible increase in livestock farming in high mountain areas could delay the altitudinal progression of forest vegetation, although it would also accelerate the species turnover of the herbaceous flora.

Land use planning and environmental assessment

Several of the adaptational options mentioned need to be planned from the perspective of a type of land planning that takes into consideration the impacts of climate change, in order to minimise the synergic interactions between climate change and changes in uses. Within the new framework for sustainability to be established as the climate changes, environmental impact assessment will have to consider the interactions between the environmental impacts of projects and impacts deriving from climate change. With regard to plant diversity, and within this new framework, we must begin to evaluate impacts such as the fragmentation and reduction of habitats, the introduction of exotic flora, the intensification of uses, excessive water consumption associated with certain uses (see Chapter 3), or effects upon habitats that are unprotected but which could constitute important areas for the redistribution of vegetation. The development of strategic environmental assessments and the application of these to the issue of biodiversity conservation (Díaz *et al*. 2001) are tools that could contribute to the necessary change in scale and perspective.

5.6. REPERCUSSIONS FOR OTHER SECTORS OR AREAS

The ecological role of plants as primary producers means that changes in flora and vegetation will have direct or indirect effects on almost all the sectors considered in this Report. Loss of floristic diversity will affect the different goods and services provided by biodiversity. These losses are especially relevant in the case of Spain, because our country houses a high proportion of Europe's biodiversity as was pointed out in section 5.1. The following is a succinct enumeration of these connections.

Changes in the structure and composition of vegetation in turn have effects on climate, through modifications of the albedo, changes in carbon balances, emission of VOCs, and, through interactions with the fire regime, they also contribute to CO_2 emissions. The relationships between plant diversity and the functioning of terrestrial ecosystems, continental aquatic ecosystems, coastal areas and edaphic and hydric resources in general have been described in the corresponding Chapters (2, 4, 7 and 8) and in section 3. Interactions between plant and animal species are particularly important for both of them, are sensitive to changes in phenology and distribution caused by climate change, and they have been mentioned in Chapters 2 and 6 and in section 3. The relationship with natural risks is mainly established through fires and surface erosion processes (Chapter 12). Phenological modifications, changes in plant productivity and in the chemical composition of phytomass and flora displacement will have repercussions for the agriculture and livestock farming (Chapter 10) and forestry (Chapter 9) sectors; in turn, the interactions between changes in the uses associated with these sectors and climate change, constitute one of the most important determinant factors of the future dynamics of plant diversity. According to the World Health Organisation (WHO 2003), one of the consequences of climate change that is insufficiently known and which requires continuous follow-up refers to changes in air pollution and the associated aero-allergenic levels. With regard to the latter, changes in the flowering schedule of many species (García-Mozo *et al*. 2002a) would give rise to a prolongation of pollen in the air, with the consequent repercussions for health: an increase in the number of patients with allergy and in the duration of the allergic symptoms, the associated increased pharmaceutical expense, higher work and school absenteeism, increased hospital emergency admissions and even changes in the temporality of tourism. This health problem has implications at local, regional and even national level. Also related to tourism, it should be pointed out that certain degradation processes of plant cover that could be caused by climate change, such as deforestation caused by drought, plagues or fires, erosion, homogenisation of landscapes, etc., would involve losses of natural attraction for potential visitors, and this could locally affect tourism demand and the economy that depends on this sector.

5.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

Uncertainties involving the possible impacts of climate change are mainly based on our ignorance of how the different factors in play will come together in time. Thus, for example, we avail of reasonably reliable climate series that describe the situation of climatic elements within one century, but effects on plant diversity might be substantially different, depending on the temporal trajectories of the changes, especially in relation to rainfall. The incidence of extreme events and changes in climatic stochasticity are more difficult to accurately predict, but, from what we know, these direct and indirect effects could be more intense and irreversible than those produced by average climate tendencies (Walther *et al*. 2002).

Synergies between climate change and other components of global change (related to atmosphere and land uses) constitute another of the elements of uncertainty. The signs indicate that the latter will generally accentuate the impacts of climate change, especially in relation to aridification.

Responses by species also constitute another source of uncertainty, due to the variability to be expected, which has been verified in the sign and magnitude, and in the response times. The high number of species involved increases this uncertainty, and this is an aspect that therefore requires great effort with regard to research, which should foreseeably be based on the definition of the functional attributes of species conditioning their types of response. The uncertainty is greater in that species interaction will play a decisive role (see section 3.1), because the modification of these interactions can in many cases cancel out the individual responses to be expected.

Lastly, the temporal and spatial scales of the impacts represent another of the challenges in research of climate change. Most of the information on biological responses has been obtained at individual, population or community scales, but effects at landscape or regional scales are more difficult to model, and therefore, to predict. Furthermore, the spatial resolution of future climate projections have not yet reached the detail of the mesoclimatic variations induced by topography and relief, which could be vital for the subsistence of communities and species in refuge enclaves.

5.8. DETECTING CHANGE

The signal of climate change confirmed to date is still moderate (see section 5.3.1) and the effects are therefore beginning to be detected only partially. The most extensive and tangible evidence concerning plants in our latitudes refers to changes in the phenology of certain species and to the growth patterns detected in the annual rings of trees (Hughes 2000, Walther *et al*. 2002, Gitay *et al*. 2002). There is also evidence of changes in the composition of certain communities, of movements of flora, both autochthonous and invasive, and even of the virulence of certain plagues, which have been interpreted as consequences of climate change. This evidence, referred to in section 5.3.1.4, is often difficult to separate from other impacts of global change and, in any case, there is not yet a sufficient body of data to constitute an indicator. We also avail of studies that should how the impacts of climate change can occur in plants, and of evidence of the effects of other components of global change (chemical composition of the atmosphere, changes in land uses) on plant diversity, which are also referred to in section 5.3.1.

The magnitude and complexity of the foreseeable impacts therefore call for more detailed follow-up, in order to confirm responses expected and to predict the unexpected ones in time. The indicators of change assigned here are those that can provide information that is disassociated from the effects of other components of global change, for which previous series of data are available to establish references and projections, and that can provide in the short or medium term values indicating the magnitude of the effects of climate change upon plants. Furthermore, the interpretability of these data, the existence of international databases, the comparability of these and the validation methods are now sufficiently established or can be developed with little effort (Erhard *et al*. 2002). Other indicators the future development of which is considered to be feasible and recommendable are described in section 5.10.

Phenological databases

Different phases of the life cycle of plants depend on the annual course of the climate, especially in extratropical climates. This physiological triggering of these phases is controlled by temperature in many plants, and the response by these to climate change is one of the first ones to be recorded. It should be kept in mind, however, that, depending on the species and life cycle phases considered, this control could be exercised by other factors, such as photoperiod, water availability or even by combinations of factors (Larcher 1995).

But for sensitive species, flowering and foliation have been advanced in the last 3-5 decades at a rhythm of between 1.4-3.1 days/decade in Europe and somewhat less (1.2-2(3.8)) in North America (Ahas 1999, Chmielewski and Rötzer 2002, Menzel and Estrella 2001, Menzel *et al*. 2002, Walther *et al*. 2002). The changes are less consistent in the summer or autumn phases (Bradley *et al*. 1999, Menzel *et al*. 2001, 2002), but in Europe, the withering of the leaves of deciduous species is being retarded by between 0.3-1.6 days/decade. As a result, the period of vegetative activity has been increasing by an average of 3.6 days/decade over the last half century (Menzel and Fabian 1999, Peñuelas and Filella 2001). These values do not deviate greatly from those deduced from the analysis of vegetation growth periods through satellite images (Myneni *et al*. 1997) and of annual cycles of atmospheric CO_2 concentrations (Keeling *et al*. 1996), which also indicates that the lengthening of the period of vegetative activity has become more evident in the last two decades. Phenological modifications do not occur in a territorially homogeneous fashion, and allow areas to be detected in which warming does not occur at the same rhythm, as happens in parts if SE Europe (Menzel and Fabian 1999, Chmielewski and Rötzer 2002), or even cold spells recorded throughout the last century (Ahas 1999). The data available in NE Spain (Peñuelas *et al*. 2002) show advances of 1-5 weeks in foliation and of 1-10 weeks in flowering for the last half century, and delays in leaf shedding of 1-2 weeks, with mean values in the response that should be considered high in comparison with those of the European context. The responses are very variable among species; with regard to phenological advance, herbaceous and early flowering plants respond better than woody species and, in general, late flowering ones (Post and Stenseth 1999).

Thus, phenological studies are a powerful tool for the follow-up of the biotic response to climate change and, in spite of the fact that classical registers of phenological data have been criticised by different sectors of the scientific community, they have now been very much revitalised for this reason (Lieth 1997, Schwartz 1999, Wuetrich 2000, McCarty 2001, Menzel 2002). In the European framework, the main initiative in this context is the *European Phenology Network*, EPN, www.dow.wau.nl/msa/epn), created for the standardisation of procedures (Bruns and van Vliet 2003), for the co-ordination and integration of information and work groups (Bruns *et al*. 2003, Schwartz 2003) and for the development of education programmes. An attempt has been made to promote international phenological follow-up networks by GLOBE (*Global Learning to Benefit the Environment*) (Peñuelas and Filella 2001).

Aerobiological databases

Aerobiology is being used as a tool for the study of the male floral phenology of many plants pollinated by wind, due to the fact that the presence of grains of pollen in the air is a consequence of the phenological state of flowering. In this sense, aerobiological databases are proving to be useful for these studies, because temporal series of at least 20 years are available in several countries. Aerobiological data are collected on a daily basis with devices that suck constant volumes of air, which allows the evolution of floral phenology to be studied in detail. These apparatuses have a weekly autonomy and a cover of around a 50 km radius, depending on the topography and the capacity to disperse pollen grains of the species to be studied.

The Spanish Aerobiology Network (REA, Red Española de Aerobiología) manages about 50 sampling stations distributed throughout the country. Recently, it has been created the Red Portuguesa de Aerobiología (RPA, Portuguese Aerobiology Network) which, together with the REA, provides knowledge of the airborn pollen content throughout the whole Iberian Peninsula. Although the REA was formally set up in 1992, at certain sampling points it avails of continuous data from 1982. This database is highlighting the sensitivity of the different species to climate change.

Herbaceous species have a different behaviour pattern than woody plants. In the Mediterranean area, development and flowering depend more on rainfall regime, and the effects of temporal distribution are more important than the total quantity recorded (Emberlin *et al*. 2000). The influence of climate change has not been very marked up to the present, as the main changes have been seen in temperatures. A change in rainfall regime towards a greater torrentiality or a seasonal redistribution of rainfall would increase the effects.

With regard to woody species, temperature is the factor which most affects the development of the flower buds of trees that flower in early spring, such as the Holm oak, whereas the trees that flower later, like the olive or the cork oak, are more affected by the photoperiod (García-Mozo *et al*. 2002; Galán *et al*. 2001, 2004; see also Osborne *et al*. 2000). An advance in budding date of the trees and of flowering in general could make them more vulnerable to late frosts. An increase in temperature would accelerate the development of buds and flowers. Likewise, different responses have been observed in one same species depending on the geographic area, which is to be expected if we take into account the different magnitudes and directions of climate change according to territories.

At the European level, work is being done in this line using aerobiological data, through a European network, the *European Aeroallergen Network* (EAN), to which the REA belongs, and which is also co-ordinated with the EPN. Different studies have highlighted a generalised advance at European level of the pollen season of different species (D'Odorico et al. 2002, Emberlin et al. 1997, 2000). Most of the available pollen series in Spain are still too short, but they appear to indicate an advance in the flowering of many tree species. This advance is more consistent for the pollen season of *Quercus* at inland sites of the Peninsula (García-Mozo *et al*. 2002a, b). Using aerobiological and meteorological databases it has been possible to build models for the climatic determinants of flowering of some species. Applying these models to climate projections for the next century, it has been foreseen advances of up to 6 weeks in flowering time for early-flowering oaks in areas of central Spain like León or Madrid.

The increase in productivity induced by the elevation of CO_2 atmospheric concentration also implies a higher production of pollen by anther, as it has been experimentally proved (Rogers *et* *al*. 2004). Pollen series from different European stations show an increasing trend in the airborne pollen concentration. Such evidence is not clear in Spain still, probably due to the high interannual variability which will require the availability of longer series of pollen data.

The aerobiological data can be shown by means of tables and graphs that are easily interpreted by the people in charge of evaluating the results of the follow-up. The REA has much experience in the dissemination of aerobiological data, this being one of its main objectives since it was set up. Data must be statistically analyzed to prove that tendencies are not the result from interannual fluctuations of climate.

Dendrochronological database

Growth in thickness of trees, calculated using the annual growth rings, is related to climatic conditions, and can be used to confirm the effects of climate change. Dendrochronological and dendroclimatic studies are relatively recent in Spain, as they practically began with the studies carried out by Creus and Puigdefábregas in 1976 and 1983. Since 1984 dendroclimatology has been developed through studies of species of *Pinus* and of deciduous *Quercus,* apart from some other genera of conifers and of the oak family. Among the researchers who have most contributed to these activities, we can highlight J. Creus, A. Fernández-Cancio, R. Génova, M. Génova, E. Manrique, K. Ritcher, E. Trobajo, E. Gutiérrez, and A. Pérez-Antelo.

The dendrochronological database used as a reference for researching climate currently has 1,064 series, of which 940, corresponding to 574 trees, are of great interest due to their longevity and sensitivity (Table 5.6). The chronologies cover a time interval from 1050 to 1997. In dendroclimatic studies, the information supplied by the weather stations started to be of use in the year 1945, and the 1945-1997 interval was used to calibrate and verify the models. Spatially, the cover of the Peninsula is complete, as a new methodology has been developed (Fernández-Cancio and Manrique 1997) which, using the classical reconstruction systems of the Tree Ring Laboratory (Tucson, Arizona), allows for the reconstruction of any monthly meteorological variable in those stations that have at least 50 years of instrumental records.

This method is based on the selective reconstruction of each variable, correlating it with the total from the database. The model applied is calibrated and verified and its statistical reliability is analysed through comparison with random simulations from climate records, according to the distribution of the data on the real variable. Thus, 57% of the variables can be reconstructed in a reliable manner. In the year 1300, the variance started to become stable, and after 1500 the reconstructions are valid for the whole of the territory. The scope of the climatic signal for temperatures is very great, as it reaches the Canary Isles in the South and it has not been determined to what part of Europe in the North. For precipitation, however, the degree of reliability is much lower. The Little Ice Age (LIA) is completely defined, as is the evolution of the climatic variability (Manrique and Fernández-Cancio 1999, 2000). Spatially, the whole Iberian Peninsula can be reconstructed (Candelas 2000).

The signal (Fig. 5.7) tallies quantitatively with the tendencies detected in the climate evolution of the Northern Hemisphere (www.ngdc.noaa.gov/paleo/recons.html). Some of the chronologies obtained have been incorporated into the Geophysical Database of dendrochronological character of the NOAA *Paleoclimatology Program* through the *International Tree Ring Data Bank* (ITRDB). As can be seen in the standardised reconstructions of the millennium in 320 Spanish stations (Fig. 5.7), the precipitation and temperature episode in the last half century, essentially warm and alternatively humid and very dry, appears to show unique characteristics in Spain with regard to tendencies and variability of the last 1,000 years. From this point of view, we can speak of present climate change in relation to the tendencies of the last millennium.

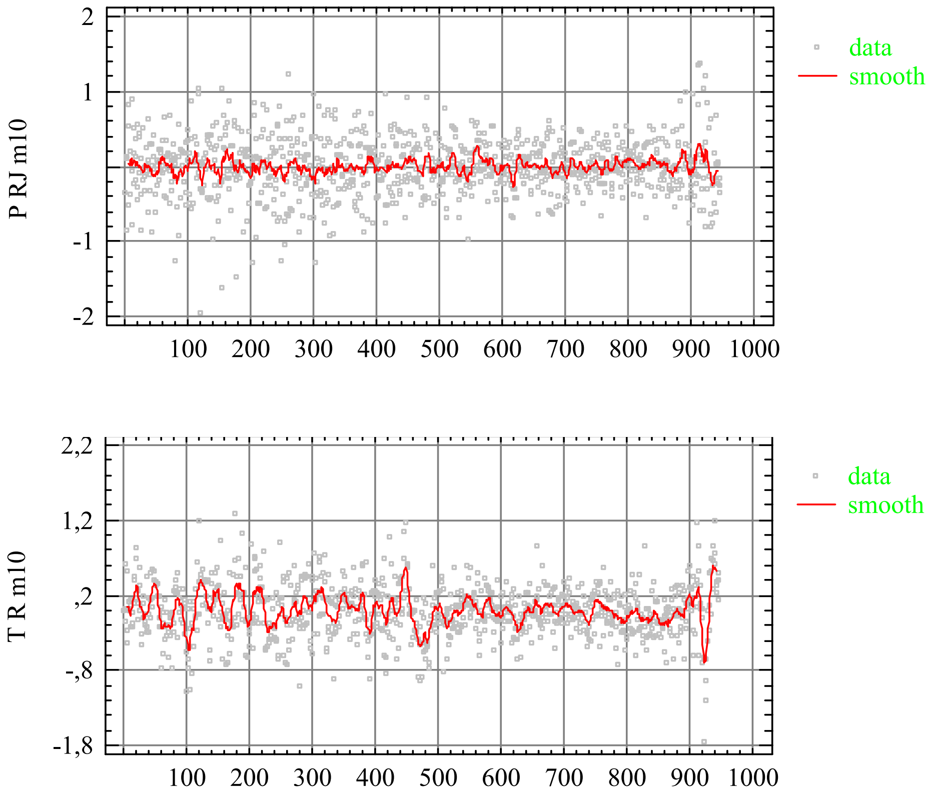

Fig. 5.7. *Representation of precipitation (above) and mean temperature (below) standardised and dendrochronologically reconstructed for 320 stations and their moving averages over 10 years. The temporal interval reconstructed (in abscissas) covers the period from 1050 to 1997. Patterns of high variability are observed from 0 to 400 and the anomalous behaviour of the last 50 years, which corresponds to real data.*

Table 5.6. *Zones and characteristics of the dendroclimatic database*

Zone	Number of series	Number of trees	Species	Maximum length of the series (years)
Guadarrama	259	134	*Pinus nigra*	505 (La Jarosa)
Cuenca	150	91	*Pinus nigra*	629 (Uña)
Galicia	59	40	*Quercus spp.*	432 (Invernadero)
Gredos	43	22	*Pinus nigra*	322 (Piedralaves)
Demanda-Urbión	129	76	*Pinus uncinata*	528 (Vinuesa)
Pyrenees	98	65	*Pinus uncinata*	690 (Aigüestortes)
Alcaraz-Segura	74	50	*Pinus nigra*	409 (Paterna)
Cazorla-Filabres-María	60	40	*Pinus nigra*	939 (Sierra de Cazorla)
Teruel	68	56	*Pinus nigra*	410 (Bellena)

It is possible to locally identify, in each weather station, the behaviour and evolution of the present climatic episode. The additional reconstruction of the climate enables us to detect the impact on vegetation, and, as a result, the changes tendencies therein can be analysed, simulating current and future displacements. An ARIMA analysis of the temporal series also enables us to get a qualitative idea of the predictions over the next ten years. The managers of the forestry, hydrology and population protection sectors could be the main beneficiaries of these predictions.

Remote sensing

The information provided by the remote sensors installed in the satellites has multiple environmental applications, among which are recent and important contributions regarding the impacts of climate change on vegetation. Analysis of the temporal series of the standardised difference vegetation index (NDVI) has confirmed the lengthening of the vegetative period in the northern hemisphere (Myneni *et al*. 1997, Chen and Pan 2002). Available since the 70s, the series of satellite images also enable us to quantify, with increasing resolution, changes in uses and plant cover in territories, and through these, changes in landscape structure, one of the indicators of biodiversity considered to be most promising (Fernández-González 2002). With the use of temporal series, biogeographic limits can be characterised that are independent from the different types of present vegetation (Lobo *et al*. 1997), and these could be used in the follow-up of vegetation displacements brought on by climate change. With modern sensors, it is becoming possible to evaluate with increasing resolution the water content, the physiological state or the growth of the vegetation. Technology based on remote sensing therefore constitutes and important tool for the follow-up of the impacts of climate change.

5.9. IMPLICATIONS FOR POLICIES

The objective of reaching sustainable forms of development has met with a big problem in climate change. The European Union recently established, in the Göteborg summit (2001), the commitment of halting losses of biological diversity within its territory by 2010, as an inherent implication of environmentally compatible development. Avoiding the added losses of biodiversity derived from the impacts of climate change, a global conflict requiring global measures, is a challenge difficult to deal with through local measures, the efficiency of which is always limited. The sectorial policies affected by the impacts of climate change on plant diversity were mentioned in section 5.5 and are fundamentally related to the responsibilities of the regional autonomies or local administrations. Thus, on one hand, the strategies designed in this respect require a broader geographic framework in which they can be co-ordinated and integrated. On the other hand, within the framework of the initiatives deployed by the EU, the large proportion of European biodiversity contained in Spain should be highlighted. The magnitude of the foreseeable impacts of climate change make advisable a thorough revision of the Spain's Strategy for conservation of biodiversity (MIMAM 1999).

Land use planning should incorporate consideration of the impacts of climate change, at least in an attempt to minimise the negative interactions between these and changes in land uses, in particular with regard to the effects of infrastructures and housing on the fragmentation and degradation of habitats and the geographic displacements of other uses brought about by climate change. The management of natural resources is faced with considerable changes in the productivity of forestry, agriculture and livestock farming, in the future location of these and in their modalities of intensification, in contexts that will be difficult to sustain in many cases. The environmental quality and evaluation area will also have to assume the new framework of interactions generated by climate change; the application of strategic environmental evaluations, instead of evaluations of the individual impact of each project, could contribute to the change in perspective.

The protection of nature, together with ecological restoration in the broad sense, is the sectorial policy most directly involved in the impacts of climate change on biodiversity, as has been indicated in section 5. These impacts are starting, and will do so to a much greater extent in the future, to throw light upon the value of ecosystems and the direct and indirect benefits the offer to humankind, which, unfortunately, are too often underrated, especially with regard to economic appraisal. It is therefore the time to call attention to this through environmental education and awareness programmes, in order to pave the way for sectorial policies capable of attenuating impacts and to involve administrations and citizens in their development and implementation.

5.10. MAIN RESEARCH NEEDS

Research into the impacts of climate change on vegetation can be structured into three main, interconnected lines: follow-up of the real changes occurring or that will occur, the responses by species and communities to foreseeable changes and the design of predictive models, based on the information provided by the previous ones and on climate projections, in order to anticipate the floristic and plant changes to be expected. The continuity of the follow-up will allow the degree of fit of the predictions by the models to be contrasted, and to introduce, where necessary, and with sufficient advance, measures for correction or attenuation of the impacts.
Follow-up activity currently comprises several unequally developed levels. We should promote the participation of research groups in the phenological follow-up networks, given that current participation is very low (for instance, there are only two groups in the EPN, apart from the REA). Furthermore, it is unlikely that research groups will become involved in long-term follow-up without any guarantee of financial backup. With regard to aerobiological follow-up, although there are a large number of aerobiological stations in Spain run by the REA, there are also big geographical areas that are insufficiently covered, such as Castilla y León and Castilla-La Mancha. This, along with the costs of maintaining the collector equipment and in particular of the interpretation of the samples, which require many hours of analysis at the optical microscope, constitute the funding needs of the network, which have been heretofore provided by the public administrations in exchange for the information generated for alergolology applications.

The possibilities of applying the dendrochronological database as an indicator of climate change still require methodological developments. Full comprehension of the scope of the present disturbance and of its characteristics can be attained by seeking more long-lived trees over 500 years, and by analysing fossil and sub-fossil wood, with which to strengthen the signal of the warm early-medieval period (1000-1300 AD) and the preceding big climatic episode (600-1000 AD).

Apart from the development of follow-up based on remote sensing, as was pointed out in section 8, follow-up in the field of floristic changes and changes in vegetation constitutes another vital element. The most interesting approach would consist of articulating a network of plots for permanent follow-up, representative of different habitats and landscapes with differing degrees of vulnerability to the effects of climate change, and suitably distributed according to Spain's biogeographic units. The network of protected areas could constitute a framework for the location of the follow-up points, because these provide an acceptable level of control of land uses and avail of backup cartographic and floristic information. The initiative could be co-ordinated with the follow-up plans required by the Natura 2000 network and could benefit from the possibilities of co-funding by the EU. Apart from periodic sampling of floristic diversity at different scales of spatial resolution, the incorporation could also be contemplated of the phenological and demographic follow-up of keystone species or of those selected and representative of different models of response to climate change. The follow-up procedures should be able to be linked to procedures of adaptative management in order to evaluate the effects on biodiversity of specific actions and the interactions of these with climate change. About the monitoring of high mountain habitats the EU research project GLORIA-Europe is functioning with a network of permanent plots in the summits of 17 European ranges, including Sierra Nevada and the Pyrenees (Pauli *et al*. 2004; www.gloria.ac.at). This initiative is been enlarged at the global scale through GLORIA-Worldwide. The network of plots for the follow-up of forest damage (Montoya and López Arias 1997), should also maintain its activities, which are necessary for evaluating the effects of droughts and plagues.

In the same sense, and in the frame of the Atlas of Threatened Flora (Moreno Saiz *et al*. 2003), a project of population monitoring has begun for 40 endangered plant species, which will allow to detect future trends in these species and draw conclusions and management recommendations. This demographic monitoring should be accompanied by genetic studies (breeding systems, levels of endogamy, genetic diversity within and among populations) to properly evaluate the vulnerability and the importance for conservation of the different populations (Hampe 2004). Another complementary network we could consider is the one dealing with the follow-up of post-fire regeneration after forest fires, because big changes are to be expected following these disturbances.

In dealing with the responses by species and communities to climate change, experimental and fieldwork approaches are needed. The latter, like the aforementioned follow-up systems, should have a long-term focus, due to the characteristics of climatic processes and to the fluctuating nature of Mediterranean climates. The lack of this type of long-term approach in our country has been pointed out by numerous researchers (Moreno and Fellous 1997, Herrera 2001, Zamora *et al*. 2001, Hampe 2004). Modification of inter-species interactions, the characterisation of functional groups of plants with similar responses to climate changes and the evaluation of indicators of the effects of climate change on biodiversity (Díaz 2002, Fernández-González 2002) are some of the priority themes in this respect.

Lastly, the development of predictive models of the dynamics of floristic diversity under the pressures of climate change, will constitute the most elaborate tool for generating projections, designing mitigation measures and evaluating their efficiency (Nualart 2003, Thomas *et al*. 2004). The models should progressively incorporate resolutions at landscape and regional scales, the effects of fragmentation, capacities of the species for dispersal and migration, indirect effects of climate change and interactions with other components of global change. All these respects need technical development. The reliability of the projections depends upon the quality of the information about floristic and vegetational diversity. Databases on the distribution of floristic and plant diversity in Spain is beginning to gain importance, although there are still shortcomings in relation to the spatial resolution of the data, and above all, in the compilation of the very dispersed documental sources coming from publications, cartography and scientific collections (herbaria). Support is needed for the initiatives aimed to computerize this kind of data, among which are at the national level the project Anthos (www.programanthos.org), carried out by the Botanical Garden of Madrid, that has compiled more than 700000 floristic records in Spain, and the Data Bank on Biodiversity of Catalonia (BDBC, http://biodiver.bio.ub.es/bioca), with similar aims but restricted to the Catalonian countries. At the international level are the Global Biodiversity Information Facility (GBIF, www.gbif.org) and the Biological Collection Access Service for Europe (BIOCASE, www.biocase.org). The Atlases of Threatened Flora and of Natural and Seminatural Habitats, promoted by the Direction General for Biodiversity Conservation (Ministery of the Environment), constitute other relevant milestones in this direction, which still requires the compilation of the huge phytosociological databases, only in part published, and the widening to other componentes of vegetal diversity. The usefulness of these data in studies about the impacts of climate change will require a good accuracy in both georeferentiation, with spatial resolution at 1 km^2 or more detailed, and in chronoreferentiation (date) of the records.

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6. IMPACTS ON ANIMAL BIODIVERSITY

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ABSTRACT

Spain, possibly the EU's richest country with regard to animal species, has the highest number of endemisms. The number of new species described every year indicates that a high percentage of the fauna remains unknown. Greater effort is required in our country with regard to taxonomic research. There exists much evidence of climatic effects on the biology, abundance and distribution of vertebrates and of certain groups of insects of our fauna, and there are very little data on most of the invertebrates.

There are two future scenarios of the effects of climate change on the biodiversity of vertebrates: 1) Ecosystems will be displaced jointly in accordance with climate, and 2) ºEcosystems will adapt and change. The first scenario is unrealistic, due to the tremendous and growing fragmentation of habitats in Europe and the complexity of the responses by the different species and of the interactions between them. A possibility of displacement of the biocenoses only appears to exist in rivers. The second point does not allow for accurate predictions in most cases in view of the current level of knowledge.

There is evidence of the direct effects of climate change to date, in spite of the scarcity of good temporal series. Thus, large phenological changes have been detected in populations of vertebrates and invertebrates, with advances (and in certain cases delays) in processes of initiation of activity, the arrival of migratory species or reproduction.

The maladjustment between predators and their prey resulting from differential responses to climate is another detected consequence of recent changes.

The distribution of certain species is being displaced towards the North or towards higher altitudes, which for certain mountain species is involving a clear reduction of their areas of distribution. Likewise, in rivers the displacement has been observed of thermophilous species upstream (particularly of molluscs), whereas the proportion of cold water species is diminishing (especially of insects). In lagoons and lakes it has been seen that altitude, latitude and depth have similar effects upon communities, which appears to be related to temperature.

There is some evidence of greater virulence of parasites or of an increase in populations of invasive species, in general more adaptable to environmental change that may be dependent on climate change.

The deterioration of fragile habitats such as small bodies of water, springs, small streams and isolated forests due to desiccation or fire or the disappearance of food plants of limited distribution could seriously affect animal populations and even lead to species disappearance, above all of invertebrates.

Neither the displacement of distribution areas (hypothesis I) nor the rapid adaptation to new ecological conditions (hypothesis II) appear to be viable solutions for most of the species studied.

Among the areas most vulnerable to the effects of climate change, we could include coastal areas, wetlands, permanent water courses that would become seasonal, seasonal ones that would have a more irregular flow or would even disappear, high mountain areas and humid pasturelands.

The main adaptational solutions should include the design of reserves and nature parks to allow for the possibility of migration and changes in distribution by means of interconnecting biological corridors. The network of protected areas should incorporate latitudinal and altitudinal gradients

to enable the protection of populations with geographic distributions undergoing processes of geographic displacement resulting from climate change.

It would be interesting to promote the classification or creation of “zones or areas especially sensitive to climatic change”, for those areas with unique, original ecosystems or threatened or endemic species that cannot opt to change their habitat and that may become extinct. Examples of these zones are high-mountain areas or springs, streams or other water- courses containing endangered or vulnerable species.

The conservation of biodiversity ought to pay attention not only to the protected areas, but also very particularly to the generalised promotion of land uses that are compatible with conservation and capable of counteracting the effects of climatic change.

The increase in the demand for water for human use, due to temperature increase and in a possible context of prolonged droughts, might possibly determine an increase in technological solutions that do not take into consideration the impacts on the biodiversity of animals that depend on the maintenance of aquifers and of permanent water courses.

Reforestation could have positive or adverse effects on faunistic diversity depending on how it is implemented. In any case, it will affect the taxonomic composition of the edaphic fauna.

It is necessary to promote research into taxonomy and in relation to long temporal series, both at specific and community level, and to prevent the deterioration or progressive disappearance of sources of information such as the phenological database of plants and animals (birds and insects) initiated in 1940 by the Agricultural Meteorology Service, belonging to the National Meteorology Institute (INM).

6.1. INTRODUCTION

6.1.1. Vertebrate fauna in Spain

The number of vertebrate species existing in Spain has been calculated with a reasonable degree of accuracy (see recently published Atlas and *Libros Rojos* - red books). Around 51,000 species or 4,1% of species described worldwide are vertebrates (Ramos and Templado 2002 and Table 6.1). On the Iberian Peninsula, approximately 1,180 species have been estimated, including continental and marine fish and among the birds taking into account only the residents and reproducers (Ramos *et al*. 2002), which would constitute less than 2% of all the animal species existing in our country. There are around 118 species of mammals, 368 species of birds, 61 species of reptiles and 29 species of amphibians. In amphibians, reptiles and mammals, this figure can vary slightly, according to the taxonomic criterion used, but the greatest discrepancy occurs with the least known and most diverse taxonomic group, marine and continental fish, of which there could be around 750 species (Doadrio and Ramos, pers. com.). With reference to the known number of different kinds of vertebrates in Europe, Spain is the country with the highest number of described species and the highest proportion of endemisms (8%, compared to the next ranking country, Italy, with 4%) (Ramos *et al*. 2002). Unfortunately, it is also the country with the highest number of species in danger of extinction, 7% (Ramos *et al*. 2002). Spain is therefore a key country in the preservation of the biodiversity of vertebrates in Europe. We must highlight the high rate of endemism of the vertebrate fauna of the Canary Isles. All the 14 species of reptiles in the Canaries, except for one introduced species, are endemic. With regard to birds, the number of endemic species is higher than in the rest of the country, ranging from 4 to 6 species, depending on authors.

6.1.2. Invertebrate fauna in Spain

The extraordinary environmental variety in Spain, in which four of the six biogeographic regions of the European Union are represented (Mediterranean, Atlantic, Alpine and Macaronesian), as well as 60% of the habitats of community interest included in the Red Natura 2000 (Hidalgo 2002 and Chapters 2, 3, 4 in this book), endows our country with a high diversity of animal species. The combination of causal factors of this biodiversity, in terms of geographic position, orography, climatology, lithology and palaeobiogeographic and sociological factors, were revised by Ramos *et al*. (2001) and are summarised in Chapter 5. The huge diversity of ecosystems and unique habitats, both in the Peninsula and the archipelagos of the Balearic and Canary Isles is not only seen in the high number of species (approximately 50% of those inventoried by the projects *Fauna Europaea* 130,000 species, and *European Register of Marine Species* (ERMS) 25,000 species), but also in a high percentage of endemisms (over 50% of Europe's endemic species), especially considering that our territory represents less than 6% of European territory.

Although complete inventories of the species described in Spain (http://www.fauna-iberica.mncn.csic.es/), are not yet available, it is estimated that in our country there are around 68,000 animal species (Ramos and Templado 2002 and Table 6.1). The invertebrates undoubtedly constitute the greatest contribution to animal diversity in the terrestrial environment and in the freshwater, brackish and marine ones of the Peninsula and the Archipelagos. Around 98% of the species of our fauna are invertebrates and of these, around 76% are insects (around 50,000 species). Although the figures for non-insect invertebrates are relatively low compared to those for insects, they make a noteworthy contribution to the biodiversity and to the life processes of the planet. With regard to life forms, whereas all the insects belong to one same group of arthropods, with the category of Class in the Animal Kingdom, the remaining invertebrates with representatives in Spain belong to 32 of the 33 groups with the category of *Phylum* described on the planet, which indicates a large number of independent evolutionary lines, corresponding to different structural plans within the Animal Kingdom.

We have very little knowledge of our invertebrate fauna. In the last few years, certain studies have been published that compile and analyse the new taxa described on the Peninsula and the Archipelago in the Macaronesian region (Templado, *et al*. 1995; Fernández 1996 1998 2000 2001 2002 and 2003; Esteban and Sanchíz 1997). These studies record, in the 1994-2000 period, a total of 2,152 new species described in Spain (1,737 peninsular ones and 415 in the Canary Isles) of which 609 (465 on the Peninsula and 144 in the Canaries) correspond to non-insect invertebrates. This is equivalent to a description rate of 250-300 new species per year, of which 72% are insects and the rest correspond to other types of invertebrates. The data from the project *Fauna Europaea* (unpublished) corroborate the fact that the countries in the Mediterranean Basin are the ones with the highest number of species in Europe. Spain, followed by Greece and Italy, are notable for their high number of new species described yearly. The asymptote in the rate of new descriptions is still far from being reached.

Fourteen out of the 32 *Phyla* are exclusively marine, the representatives of the remaining 17 *Phyla* live both in marine and continental environments in our country (Table 6.1). Of these, nine are represented in all the terrestrial and freshwater environments, whereas another seven only live in marine and freshwater ecosystems. The *Phyla* with the greatest evolutionary success are the Molluscs, the Nematodes (a group that is still poorly known) and specially the Arthropods (which include the insects -Hexapoda- and therefore take up three quarters of the planet's biodiversity and, of our fauna).

Table 6.1. *List of the* Phyla *of living animals with an indication of their relative presence in marine, freshwater or terrestrial environments in the first column, number of described species at worldwide level in the second, estimated number of species in Spain (Peninsula and Archipelagos) in the third. This number of species is then split according to the main environments: marine fourth column, freshwater fifth and terrestrial, sixth. A question mark after a figure means that the group has been insufficiently studied and the number of species is just an estimate. An isolated question mark means that no data are available to make an estimate. (Taken from Ramos* and *Templado 2002).*

	Environ ment	**Nº described species global**	**Nº estimated species Spain**	**Nº species M**	**Nº species F**	**Nº species T**
PLACOZOA	M	2	1?	1?	—	—
PORIFERA	Mf	10,000	606	600	6	—
CNIDARIA	Mf	10,500	650	647	3	—
CTENOPHORA	M	90	20	20	—	—
MESOZOA	M-P	90	25?	25?	—	—
PLATYHELMINTHE	MFT	19,000	800?	500?	200?	100?
GNATHOSTOMULID	M	80	15?	15?	—	—
GASTROTRICHA	Mf	500	100?	75?	25?	—
ROTIFERA	mF	2,000	350	20	330	—
ACANTHOCEPHAL	MFT-P	1,200 P	50?	50?	?	?
CYCLIOPHORA	M-P	1	1?	1? P	—	—
ENTOPROCTA	Mf	100	20?	20?	—	—
NEMERTINA	Mft	900	146?	145	1	—
SIPUNCULA	M	150	35	35	—	—
ECHIURA	M	120	15	15	—	—
ANNELIDA	MFT	13,100	1,328	1,000	25	300
MOLLUSCA	MFT	125,000	2,700	2,250	120	330

NEMATODA	MFT	20,000	1,000?	300?	100?	600?
NEMATOMORPHA	mF	250	?	?	?	—
KINORHYNCHA	M	80	15?	15?	—	—
LORICIFERA	M	20	1?	1?	—	—
PRIAPULA	M	17	3	3	—	—
ONYCHOPHORA	FT	110	—	—	—	—
TARDIGRADA	MFT	800	30?	30?	?	?
ARTHROPODA	MFT					
Hexapoda	T	800,000	50,000	?	?	50,000
Myriapoda	T	15,000	500	?	?	500
Chelicerata	mfT	70,000	3,400	270	630	2,500
Crustacea	Mft	100,000	3,550	2,500	700	350
CHAETOGNATA	M	60	30	30	—	—
PHORONIDA	M	10	8	8	—	—
BRACHIOPODA	M	350	31	31	—	—
BRYOZOA	Mf	4,500	300	300	?	—
ECHINODERMATA	M	7,000	300	300	—	—
HEMICHORDATA	M	80	5	5	—	—
CHORDATA	MFT					
Urochordata	M	1,400	350	350	—	—
Cephalochordat	M	25	2	2	—	—
Vertebrata	MFT	51,000	1,792	1,180	108	504
TOTAL		1,238,535	68,179	10,747	2,248	55,184

Abbreviations
M= marine, F= freshwater, T= terrestrial, P= parasite
M= exclusively marine group
Mf= mostly marine, with some species in fresh water.
Mft= mostly marine, with some species in freshwater and in the terrestrial environment.
MFT= well represented in all marine, freshwater and terrestrial environments.
mF= mostly freshwater, but also marine.
mfT= mostly terrestrial, with some aquatic species.
T= exclusively terrestrial.
FT= exclusively terrestrial and freshwater.
P= exclusively parasites +

Molluscs constitute the most diversified *Phylum* of the Animal Kingdom after the Arthropods. Only the classes Gastropods and Bivalves are found in continental environments. They are being studied intensively in Spain where there are a high number of endemisms (above all among the terrestrial and freshwater gastropods). This number is particularly high among the land snails Helicoidea (both in Canaries and in the Mediterranean region) and among the freshwater Hydrobiids (with 90% of endemic species on the Iberian Peninsula and Balears). The freshwater bivalves include, apart from the small Sphaeriids, present in practically all the environments, the large-sized and threatened naiad species. All molluscs seem to be very sensitive to climatic factors.

If there is a group of animals that has had unprecedented success and which has an important role to play in all the ecosystems, it is the Arthropods. In addition to insects, the arthropods include spiders, mites and scorpions (Chelicerata), most of which are terrestrial, and the centipedes, millipedes, and their relatives (Myiriapoda) with around 500 terrestrial species described in Spain and a high percentage of endemisms. Crustaceans make up the other large group of arthropods which, unlike the previous ones, dominates the aquatic environment. It includes many different groups like crabs (Malacostraceans), water fleas (Amphipods), sow bugs, pill bugs (Isopods), and many plankton forms, such as many Copepods. The latter are so abundant in plankton that they constitute the animal group with the highest number of individuals on the planet. The Isopods are the dominating crustaceans in the terrestrial environment and have numerous endemisms in Spain. It should be noted that a high number of endemisms and new crustacean species (Bathynellids, Copepods and Ostracods) have been described from subterranean waters and caves, both in peninsular fresh water and in the anchihaline environment (karstic cavities and volcanic tubes flooded with stagnant seawater) in the Balearic and Canary Isles. There are also numerous endemisms among freshwater Amphipods. Most of these groups are excellent indicators of water quality and environmental changes produced directly by the climate and indirectly by anthopogenetic influence.

The insects are a particularly successful group. There is over one million currently known species of Insects, which is around 75% of all known living species, and they are involved in practically all ecological processes in continental habitats (Galante and Marcos García 1997, Samways 1994, Tepedino and Griwold 1990).

The Mediterranean Basin, one of the areas of highest diversity in the world (Myers *et al*. 2000), hosts approximately 150,000 insects (Balletto and Casale 1991), and the Iberobalearic region in Spain is the European geographic area with the highest level of diversity, it being estimated that there are around 50,000 species of arthropods, which is around 81% of all animal species in Europe (Ramos *et al*. 2001, and 2002, Martín-Piera and Lobo 2000). To this extraordinary biodiversity in this part of Spain, we must add the great entomological richness of the Canary Isles, with over 6,000 species of arthropods and an endemicity rate at around 45% (Machado 2002).

Iberian mountain ranges generally present a high number of endemisms in animal groups associated with vegetation and altitude (Martín *et al*. 2000). Furthermore, there is a high level of endemicity among other groups of species living in areas with more extreme climate or with higher rates of aridity, like the coastal areas in the Southeast of the Iberian Peninsula (Verdú and Galante 2002). This means that the Iberobalearic region has one of Europe's highest endemicity rates for insects (Galante 2002), and although the percentage varies greatly according to groups (Ganwere *et al*. 1985, Guerrea and Sanz Benito 2000, Vives 2000, Mico and Galante 2002), it could be said that almost 25% of the species associated with terrestrial ecosystems in Spain are endemic. This percentage is surpassed by far in certain groups like the Coleopteran *Tenebrionidae* in which 60.2% of the 522 species and 129 subspecies in Spain are endemic (Cartagena 2001).

With regard to the freshwater entomological fauna of the Iberobalearic region, over 25% of the species of aquatic insects known in Europe live here, with the exception of Diptera (Pujante Mora 1997). One third of the species of Trichoptera, Plecoptera and Efemeroptera found in Spanish water courses and lacustrian ecosystems are endemics with a very restricted distribution (Alba-Tercedor 2002, Alba-Tercedor and Jáimez-Cuéllar 2003, Tierno de Figueroa *et al*. 2003).

6.2. SENSITIVITY TO THE PRESENT CLIMATE

6.2.1. Role of the present climate in the distribution and biology of Vertebrate fauna

There is evidence about the impact of climate on the biology, abundance and distribution of vertebrates in Spain:

- Inventories made over 15 years in 4 sites of a small river in Asturias reveal a clear relationship between water flow in March (when the trout smolt of *Salmo trutta* emerge from the spawning grounds) and the number of the year's young trout in July (P. Rincón, com. pers.). The relationship is non-linear, showing a maximum for intermediate flow values and minimums for years of drought or heavy rainfall. These relationships have also been established in other studies (Moore and Gregory 1988a, b). In turn, the amount of trout in July accounts for over 70% of the variation in the number of adult trout 16 months later (breeding season). The areas protected from currents, associated with the shore and necessary for smolt, are more extended with intermediate currents. An increase in the proportion of dry years would reduce population size by reducing the habitat available for the smolt.

- The captures of salmon *Salmo salar* in Spanish rivers has decreased from figures of around 10,000 specimens in the 60s of last century to 20% of that figure at present. This could be related to increase in sea temperatures, although these effects could be confused with those of the overexploitation and deterioration or destruction of the freshwater habitat. Specifically, there is evidence of seriously negative effects on the capture of other species. If the temperature changes in the freshwater and marine environments are not synchronised, the death rate in post-smolt could increase (Hansen 2003). A critical period for salmon species is embryonic development. In some phases of this, particularly during hatching, there is a very high oxygen demand, and a tendency towards temperature increase in rivers could have very severe consequences for survival. More information and research is needed in relation to the genetic architecture of the characters involved (metabolic rate), the genetic differentiation of populations associated with different thermal environments, and the plasticity of the early development stages in response to changes in incubation temperature and embryonic development.

- The reproduction dynamics of the Natterjack Toad *Bufo calamita* ("a species of special interest", as indicated by the Catálogo Nacional de Especies Amenazadas) follows certain natural cycles conditioned by spring rainfall which has a clear effect on the success of metamorphosis (Tejedo 2003). These cycles can last for one decade, which suggests the need to establish temporal series of longer duration in order to understand the reality of demographic decline.

- In Spanish populations of Chameleon *Chamaeleo chamaeleon* ("a species of special interest"), the dry years give rise to a high death rate among females and a lower fertility level (Díaz-Paniagua *et al*. 2002). Long series of dry years could reduce the populations of this species. This problem is exacerbated by the reduced longevity of the species, which in many cases only reproduces once in its lifetime, rarely twice or more. This species, like many other reptiles, lays eggs covered by a flexible shell, very permeable to water. Increased soil aridity during incubation (summer) is a direct risk for these animals, because it causes a higher death rate of the eggs and less viability of offspring (apart from a higher death rate among females and lower fertility levels). One prediction of climate change is precisely an increase in the aridity of the soil, which could be particularly aggressive in the soft soils in which the chameleon lays its eggs (sand). This environmental change could affect the embryonic development and reproduction of reptiles with flexible shells in arid areas (ophidians and saurians, excluding salamanders). Field data show an extremely high death rate among eggs laid naturally, which in some cases surpasses 80% of all eggs laid, and experiments corroborate this sensitivity (Díaz-Paniagua and Marco in prep.).

- Rainfall is the best environmental predictor of the presence of several reptiles such as Schreiber's green lizard *Lacerta schreiberi* ("a species of special interest"), a saurian associated with mountain streams (Marco and Pollo 1993).

- Species like Carbonell's wall lizard *Podarcis carbonelli* present a distribution, which is very much conditioned by distance from the coast (related to humidity) in the Doñana area (J. Román, in prep.). These southern edge populations of certain distributions could be forced to withdraw by a temperature increase and/or a reduction in humidity.

- There is a high risk of extinction for certain populations of large-sized endemic reptiles in restricted areas of some of the islands of the Canary Isles, as is the case of the La Gomera Giant Lizard (*Gallotia gomerana*), whose only remaining population survives in the crags of Mérica (La Gomera) (Nogales *et al*. 2001), the El Hierro Giant Lizard (*Gallotia simonyi*, "an endangered species") in the crags of El Risco de Tibataje (Jurado and Mateo 1997) and the Tenerife speckled lizard (*Gallotia intermedia*, "an endangered species") in the Acantilado de Los Gigantes, in Tenerife (Hernández *et al*. 2000). Any alteration of environmental conditions could force them into extinction.

- Rainfall has a clear effect on the abundance of forest passerines in Iberian forests (Santos and Tellería 1995). The northern and palearctic species (many of these "of special interest") become scarcer with less rainfall. At the level of all Spanish avifauna, climate accounts for 7% of species diversity, which increases with rainfall and decreases with insolation (Carrascal and Lobo 2003).

- On the Canary Isles, especially on the more arid eastern islands, several species of birds appear to react to rainy years by advancing reproduction. In dry years, certain species (quail, corn bunting) may even stop breeding. The laurel forest pigeons, especially Bolle's laurel pigeon (*Columba bollii*, "a species sensitive to habitat alteration"), practically stop breeding in some years, which might be due to a low level of fruit production. A series of years with low rainfall could affect population size. Displacement outside the forest in search of food could lead to more damage to crops and greater vulnerability to poachers and poison. In the case of the Houbara bustard (*Chlamydotis undulata,* "an endangered species"), the different levels of rainfall among islands (Lanzarote, Fuerteventura, La Graciosa) can force movement from one island to another, with the consequent displacement costs.

- The abundance of waterfowl in the Tablas de Daimiel National Park during springtime is closely correlated to the flooded area, which in turn depends on water level and therefore, indirectly, on rainfall. This is not so for the wintering waterfowl (Álvarez Cobelas, personal communication).

- There is a correlation between the distribution of the Lesser kestrel *Falco naumanni* ("species of special interest") and rainfall in Andalucia, this species showing a preference for areas with more rainfall within this region (Bustamante 1997). There is an optimum rainfall level for the distribution of this species in Spain, close to medium-high rainfall levels (Seoane *et al*. 2003).

- In populations of common vole *Microtus arvalis* and Mediterranean pine vole *M. duodecimcostatus,* strong positive correlations have been established between abundance and spring and autumn rainfall levels in Central Spain (Veiga 1986).

- Autumn rainfall initiates the production of the rabbit *Oryctolagus cuniculus*, a keystone species in the ecosystems of Iberian *maquis* (Villafuerte 2002). Furthermore, torrential rains can be disastrous for rabbit populations (Palomares 2003). A rainfall regime marked by a higher frequency of extreme phenomena could condition the abundance of rabbits and of their predators.

- In populations of mountain goat *Capra pyrenaica* in southern Spain there is a close positive correlation between the production of offspring and rainfall in spring. Long series of dry springs could negatively affect the productivity of these populations (Escós and Alados 1991).

- In populations in Andalucia of wild boar *Sus scrofa*, reproduction in years of drought is minimal, with only 17% of females giving birth and an average litter size of only 3 offspring (Fernández-Llario and Carranza 2000).

6.2.2. Role of the present climate in the distribution and biology of Invertebrate fauna

Most of the studies of the effects of climate change on invertebrates have referred to insects. The data published on the effects of climate on non-insect invertebrates and the distribution and population dynamics of these are practically non-existent or occasional. Furthermore, with such a great diversity of animal groups, our knowledge of the geographic and biological distribution of the species is very deficient. Most of the few available data refer to experimental work, occasional observations in faunistic studies and unpublished extrapolations and observations. Molluscs are probably the best known.

It can generally be said that the vagility of the heterogeneous group of organisms that we call non-insect invertebrates is low. Their dispersal capacity is often limited to passive transport. We will therefore jointly review the few available data referring to the fauna associated with edaphic and aquatic ecosystems (lagoons, wetlands, springs, streams and rivers), as these concentrate the representatives of all the animal Phyla on the continent, and we will analyse the effects of changes on the fauna itself or the influence of this upon the ecosystems.

- The nine animal *Phyla* with terrestrial species have representatives or spend some of their life on the ground, although little is known of the genetic and taxonomic diversity of the organisms, due to the abundance and complexity of these. Ground-dwelling fauna, together with microflora, in turn, play a fundamental role in the functioning of the ecosystem: in the decomposition of organic matter, the transformation of nutrients and (together with the roots of plants) in the maintenance of soil structure and in the production of greenhouse gasses (Ingram and Wall 1998). Soil is a dynamic and highly structured substrate, the result of stable interactions among its own structure and the biota (Erhlich and Erhlich 1992). The effects of global change, through alterations in temperature, rainfall or changes in land use, can destabilise the system. Some of the alterations caused by brusque climate changes (diminished stability, increased erosion, decreases in carbon levels and microbial activity) are often masked by the effects of the chemical pollutants used in agriculture, these having a more direct and drastic influence on the biota.

- The edaphic fauna is often more conditioned by the indirect effects of climate changes on vegetation (in herbivorous species), nutrient availability and effects upon the soil itself, than by the direct effects of climate change. All the direct and indirect effects of climate change, however, cannot be disassociated from changes in land uses, which often mask or act synergically with those caused by global change. Edaphic organisms are universally present in all terrestrial ecosystems, and given the great variety of these organisms, their interactions are tremendously complex. That is, although we can learn of the individual role played by each one of their components in the ecosystem, or how they are affected by climate change, it is difficult to predict the impact of a change upon the communities they form. There are very few studies of edaphic biodiversity, although sufficient evidence exists to identify the key groups in the functioning of ecosystems, which, consequently, can be used as indicators of environmental change (Ingram and Wall 1998, Porazinska and Wall 2002). In relation to fauna, these refer above all to earthworms in moist habitats, termites in dry habitats and nematodes which, although existing in all types of soils, show a preference for certain degrees of moisture. Nematode populations appear to be very sensitive to alterations in soils and show rapid response to environmental variations over short time series, which suggests that they could also be affected by long-term climate changes (Porazinska and Wall 2002). Stability in the structure of the earthworm community (proportion of sizes among species, etc.) is essential for the maintenance of the physical properties of the soils. (Young *et al*. 1998). Ants constitute a potentially important group, although there are so few studies that the only thing that can be said is that the role they play is less relevant than that of termites (Lobry de Bruyn and Conacher 1990).

- It has been established that alterations in cycles of humidity/drought or frost/thaw, which can occur with an alteration in the intensity of the rainfall regime, have a direct influence, increasing the risk of erosion, which is undoubtedly the main source of degradation among the series of alterations that can be caused by climatic variables. The fauna most affected is the one living in soils subjected to higher risk levels, which are found in the temperate areas of the planet which includes the Mediterranean Basin (Young *et al*. 1998).

- Experimental study has been made of the effect of two climate scenarios on a community of terrestrial molluscs and their interaction with the meadow vegetation on calcareous land in the United Kingdom (Sternberg 2000). The two scenarios consisted of: 1) warm winters with increased summer rainfall and 2) warm winters and summer drought. The climatic manipulations had a significant effect upon the relative abundance of molluscs, but no changes were observed in species composition. The distribution and densities of snails and slugs were affected by changes in the physical environment and the vegetation in the grassland. The responses of the different species to the climate manipulations were strongly influenced by their phenological traits and food preferences.

- Experimental study was also made on the isolated and combined effect of an increase in CO_2 and in temperature on the behaviour and population dynamics of a generalist herbivorous mollusc, *Helix aspersa.* The number of juveniles recruited when CO_2 is high does not differ from the control population, whereas less offspring were obtained with a temperature increase. In the combined experiment (high CO_2 and temperature), however, the number of juveniles was higher than the control. The emergence of juvenile was not affected within each experiment, but these emerged 70 days earlier in the combined experiment than in the one involving temperature. In no case was any relationship observed with the quality of the foliage (C:N proportion), or with the abundance of the preferred food plant *Cardamine hirsuta.* The abundance of the species was altered in the three experiments (Bezemer and Knight 2001).

- Seven animal *Phyla* are represented in the freshwater environments (rivers, streams, lakes, lagoons, reservoirs, wetlands, springs). Invertebrates and the communities they comprise, are the most sensitive to alteration of aquatic ecosystems, due to environmental stress (warming of the water body) and human induced stress (pollution, overexploitation of aquifers, etc.), and above all, to a combination of both. The composition of the invertebrate community is consequently the best indicator of the health of the ecosystem. Increased summer drought and a decrease in rainfall will reduce the area of wetlands and biogeochemcial processes, the consequence of which for the fauna will depend on the characteristics of each system. The great diversity of the wetlands in the Mediterranean area makes it difficult to predict general patterns. We can, however, expect the more primitive, and therefore the least specialised, animal groups and species to be favoured, as they have greater plasticity and are more tolerant to stress. The consequent dominance of these species does not necessarily involve a decrease in faunistic richness, although we could expect an impoverishment of specific diversity. Some species or animal groups would respond to drought by producing durable eggs or resistant forms (e.g. Turbellarians, Branchiopoda and Rotiferans, among other), and others would do so by prolonging the pupa phase (some insects, such as the Trichoptera).

- In the case of rivers, the only study known in Europe, involving long time series was made by Daufresne *et al*. (2003). In the upper Ródano the fish (37 species) and invertebrate (92 taxa) communities were compared and inventoried from 1979 to 1999. It was observed that variability in the abundance of fish was correlated with flow and temperature in the reproduction period: low flow and high temperatures coincided with a greater abundance of fish (April-June). It was also seen that the fish species and taxa of thermophilous invertebrates gradually replaced the cold water fish and invertebrate taxa. In general, the taxa of non-insect invertebrates, molluscs in particular, which prefer medium flows with slow currents (*Potamopyrgus, Corbicula, Theodoxus fluviatilis, Physella, Valvata, Pisidium, Radix, Ancylus fluviatilis,* etc., in this order*)* were favoured*,* showing an increase in individuals and a spread upstream, compared with most of the taxa of insects studied, which show a preference for fast-flowing currents (in particular, and in this order, *Chloroperla, Protonemoura, Nemoura, Rhyacophila*, Stratiomyidae were the most negatively affected). These patterns were the most directly correlated with temperature variables, implying the causal effect of climatic warming. These *in situ* results support the predicted effects of climate change on the upstream displacement of freshwater communities.

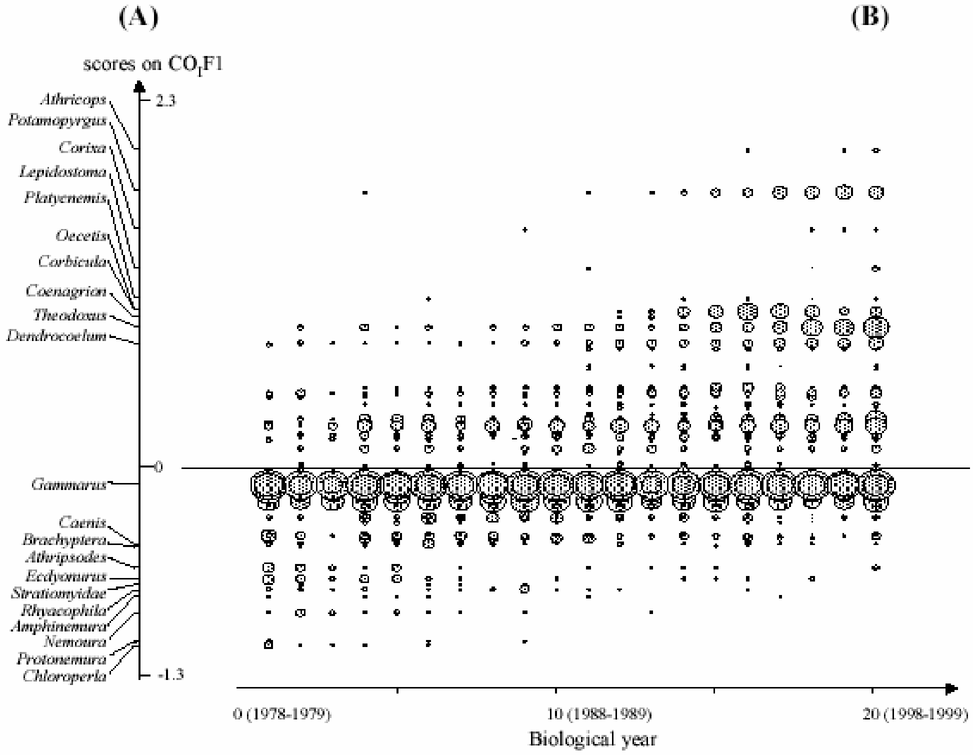

Fig. 6.1*. Evolution of the faunistic composition of invertebrate taxa of the Upper Rhone River from 1979 to 1999. Mean annual abundance per sample of invertebrate taxa (circle area and abundance are proportional) classified according to the first axis of a correspondance analysis of invertebrate data (CO1F1). Only the 10 taxa with the highest factorial scores and the 10 taxa with lowest factorial scores are given. (Figure from Daufresne et al. 2004 and kindly provided by the first author)*

- In salmon and trout's rivers, an evident decrease in fish populations can now be noted, a consequence of habitat fragmentation (Chapter 3). Among the most noteworthy effects upon invertebrates, we can highlight the negative effect of this on populations of large freshwater bivalves, which require a host fish to terminate their life cycle, with the metamorphosis of their larvae on the body of the host fish. Some of these species, such as *Margaritifera margaritifera* and *M. auricularia,* show a high degree of specificity with the host fish. In the case of *M. margaritifera* these are trout and salmon, and we can therefore expect a serious decline in their populations, which only live in the rivers in the North and in the Northwest of the Peninsula (Ramos 1998). *M. margaritifera* is protected by the Berne Convention (Annex III), the Habitats Directive (Annexes II and V), UICN (endangered). There is still uncertainty with regard to the host fish of the larvae of *M. auricularia* in nature -River Ebro and adjacent channels- (if it has not already become extinct), although it has been demonstrated that the river blenny (*Salaria fluviatilis*), could be a potential host (Araujo, *et al*. 2001). It is, however, a threatened species of fish, with fragmented populations, and the survival of both species is therefore compromised. *M. auricularia* is protected by the Berne Convention (Annex II), the Habitats Directive (Annex IV), UICN (endangered), National Catalogue of Threatened Species ("endangered"). The species *Unio elongatulus* uses several fish species as hosts, and is therefore not threatened to such a degree. This species is protected by the Berne Convention (Annex II) and the Habitat Directive (Annex V).

- The annual growth rings on the shells of *Margaritifera margaritifera* in Sweden were studied along a North-South gradient and provided a record of the growth variation over 217 years (1777 – 1993) (Schöne *et al*. 2004). The pattern observed indicates that annual growth is very much controlled by summer temperatures. The months of June-August are crucial in the more northern populations, those of autumn for the southern ones. Growth is generally greater at higher temperatures. This study highlights the fact that the shells of bivalve molluscs, generally long-lived (around 70 years) constitute excellent tools for recording climatic events, in particular, temperature variations.

Freshwater ecosystems are very sensitive to environmental stress and that caused by man, and they therefore respond more rapidly than terrestrial ecosystems to alterations. The following figure 6.2 illustrates this phenomenon.

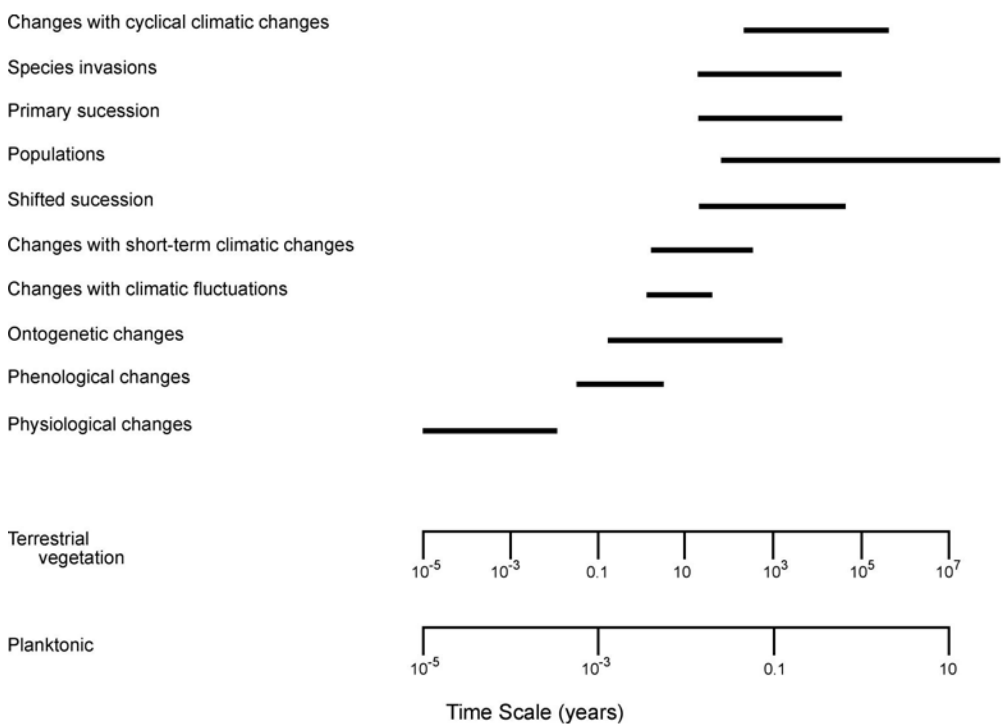

***Fig. 6.2**. Differences in the temporal scale of processes in terrestrial and plankton communities. The scale is logarithmic and the cellular processes in organisms of both environments coincides at approximately 10-5 years (i.e., 5 min). Molecular Ecology of Aquatic Microbes, Successional change in the planktonic vegetation: species, structures, scales, Reunolds, C.S., pp 115-132. 1995, (Springer Verlag, Berlin).*

Certain data exist in Spain on the effects of climate on species of arthropods and on models predicting changes in distribution or population dynamics resulting from climatic changes.

- There is evidence that the number of butterfly species in the Northeast of the Iberian Peninsula is basically conditioned by two climatic variables, temperature and rainfall. Species richness is negatively correlated to temperatures and positively to the rainfall index (Stefanescu *et al*. 2004). These data indicate that in the context of climate change, a temperature increase would lead to a clear loss of species diversity.

- The butterfly *Parnassius apollo* (Lepidoptera Papilionidae) is a species protected by the Berne Convention (Annex II), UICN 2000 (Vulnerable), CITES (Annex II) and the Directive on Habitat (annex IV). This species is widely distributed throughout Eurasia, although in a fragmented and isolated way in small populations. Numerous subspecies have been described (up to 160 throughout the whole distribution area and up to 24 in Spain). It has a discontinuous boreal-alpine distribution throughout Europe, and spreads through Siberia to Central Asia. On the Iberian Peninsula, it is found in the main mountain ranges between altitudes of 800 and 3,000 m. The main population nuclei are on the Cantabrian coast (from the Montes de Leon and Asturias to the mountains of Álava), the Pyrenees of Huesca and Catalonia, Sistema Ibérico (from the northernmost provinces to Teruel and the Valencia Regional Autonomy), Sistema Central (Guadarrama mountains) and the Betic ranges (from Sierra María in Almería to Sierra Nevada). According to the only existing study on the movement of adults, displacements are short, between 260 m and 1,840 m (Brommer and Fred 1999). Anthropic activities (especially ski resorts and high-mountain infrastructures), along with climatic change, have been identified as the main factors accounting for the regression of populations in the southernmost mountains of Spain (Baixeras 2002). It is a species generally restricted to small habitats, and any factor directly affecting the species at its lower distribution elevations would trap it within limits that are unsuitable for its survival in many places. It has been estimated that in some southern, isolated populations, like those in Penyagolosa (Castellón), an annual increase of 0.1º C could bring about the disappearance of these populations in around 30 years (Baixeras 2002).

- *Culicoides imicola* is a dipteran of the Ceratopogonidae family, a cattle arbovirus vector which causes, among other diseases, bluetongue fever in ruminants and horse fever in Africa (Wittmann *et al*. 2001), diseases included in the international lists of epizooties. It is presently known to exist in the south western half of the Iberian Peninsula (Rawling *et al*. 1997). The distribution of *Culicoides imicola* is conditioned by mean annual temperature and rainfall (Baylis and Rawling 1998). In accordance with the prediction model developed by Wittman *et al*. (2001), this species has been seen to rapidly spread its distribution area northwards. An increase of around 2º C in global mean temperature in this century could lead to a 200 km extension of the northern limit of its distribution in Europe, which would undoubtedly lead to the appearance of epizooties in Spain, which could reach northern France and Switzerland (Wittman *et al*. 2001). The predictive data on the northward dispersion of this species have recently been confirmed, with the capture of specimens in the Balearic Isles, Catalonia, and the Valencia Regional Autonomy (Sarto i Montenys and Saiz Ardanaz 2003).

- *Linepithema humile* is the so-called Argentine ant, an invasive species in many parts of the world. This species originated in Argentina and has managed to penetrate numerous urban and natural habitats of Mediterranean and tropical ecosystems. It causes serious damage in ecosystems and damage to human resources, leading to large financial losses. This species exists in Spain, and according to the existing predictive models, it will spread effectively to Northern Europe in the next 50 years, which implies its generalised presence in Spain (Roura *et al*. 2003). This would have serious consequences for the biodiversity of many habitats, through competition in some cases and predation in others.

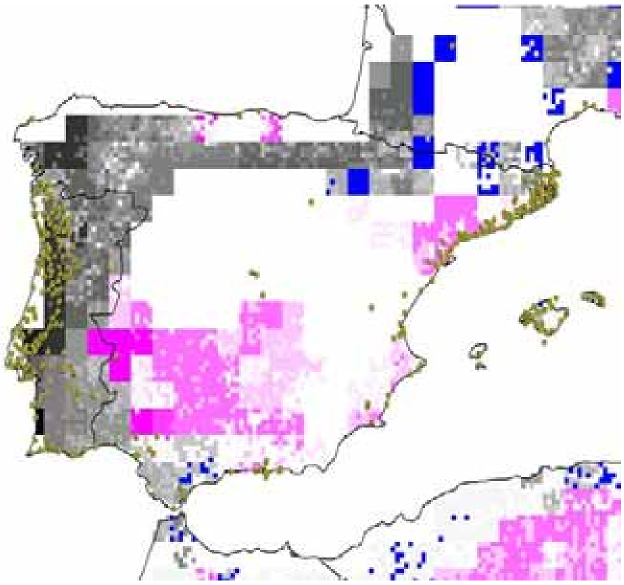

Fig. 6.3. *Modelling of the effects of climate change on the potential distribution of the Argentine Ant (Linepithema humile), an invasive species. The black-grey tones indicate the areas with the suitable conditions for the existence of the species at the present time, whereas the blue and pink tones indicate the areas to be reduced and enlarged, respectively, in the future. The dots show the places where the species exists at the present time (Extracte from Roura et al. 2003).*

- Existing data indicate that in Mediterranean ecosystems, the spatial distribution and daily periods of activity of species of Scarabaeid and Geotrupid beetles depend on temperature (Mena *et al* 1989, Galante *et al*. 1991, Galante 1992), and a thermal increase will therefore have serious consequences for the species of these groups.

- It has been observed in some species of Lepidoptera and Coleoptera in the Iberian Mediterranean environment that a survival strategy during the most unfavourable times is to retard ovarian maturation, thus avoiding immature phases at a time when food is scarce and environmental conditions do not allow for development (García-Barros 1988, Lumbreras *et al*. 1990 1991). For instance, in studies by Galante and his group it was seen how in the scarabaeid beetle *Bubas bubalus*, females appearing at the beginning of autumn copulate and store the spermatozoids in their spermatheca, without the eggs being fertilised. The ovaries reabsorb the ovules and mobilise fat reserves, which enables them to optimise their energy resources during the winter phase, and they develop eggs anew the following spring, which will probably be fertilised through further copulation (Lumbreras *et al* 1991).

- It has been demonstrated that temperature has a large impact on populations of aphids (Hemiptera Aphidinea), causing an alteration in flight periods. At present the European network EXAMINE (Exploitation of Aphid Monitoring in Europe) has made a follow-up in 19 countries over 3 years of the migratory period of aphids, using suction traps (Harrington *et al*. 2001, Hulé *et al*. 2003). Reliable data have been established which indicate a clear relationship between the population dynamics of aphids and environmental variables. Climatic variables are a sound means of accounting for at least 50% of the variation in the flight periods and range in aphids, although other factors operate at local scale, like changes in land use and habitat fragmentation.

- The EXAMINE project has shown that there is a clear relationship between increased winter temperatures and less rainfall, with an advance in the annual flight periods of aphids.

However, the main factor at work in this advance of annual flight periods appears to be temperature increase (Harrington *et al*. 2003, Seco-Fernández *et al*. 2003).

6.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

There are insufficient good temporal series with which to duly illustrate what has happened in recent times. There is historic evidence of what has happened in the last 10,000 years, such as the northward withdrawal of humid forests and the enlargement of the Mediterranean drought areas (and the Sahara, which has spread 7 degrees of latitude northwards in the last 15,000 years). From this temporal perspective, what we are now observing may only be the continuation, perhaps aggravated by human intervention, of a process that could have very grave consequences to our country in terms of biodiversity. If the predictions of the models of global circulation for the XXI century are correct, increased drought will lead to increases in hydric stress in trees and shrubs that are currently at the limit of their possibilities due to the preceding prolonged change processes. As Spain is situated in a peripheral and peninsular region of the continent (Ramírez and Tellería 2003), this could lead to the regression of many species of Atlantic origin (which would be the majority in the case of vertebrates), an increase in insularity of relict boreal-alpine species and the extinction of many populations of these "northern" organisms which currently present a noteworthy fragmentation towards the south. On the other hand, the Gibraltar straight might constitute a barrier preventing northernwards expansion of African species, which would lead to a considerable faunistic impoverishment.

Recently, the risk of extinction of 1,103 species of animals and plants in regions covering 20% of terrestrial areas was modelled with the use of predictions of climate change up to 2050 (Thomas *et al*. 2004). In a conservative scenario with global temperature increases of 0.8-1.7 º C these models indicate that 18% of the species would be extinguished, whereas in a dramatic scenario of global temperature increases higher than 2º C, up to 35% of the species would become extinct. According to this study, climate change may become the main factor of species extinction in the XXI century.

6.3.1. Future scenarios and uncertainties according to different hypotheses

There are two future scenarios of the effects of climate change on the biodiversity of vertebrates:

6.3.1.1. Hypothesis I: Ecosystems will be jointly displaced

It is based on the idea that whole ecosystems will be displaced northwards or in altitude, depending on changes in temperature and rainfall. This scenario is unrealistic due to the tremendous and growing fragmentation of habitats in Europe and to the complexity of the responses by different species and of their interactions. The impacts of global climate change have been considered on occasions as mere displacements of distribution areas, but there is evidence to indicate that displacements of distributions might increase the derived costs of biotic interactions when species occupying habitats for which they are not adapted, or in which new ecological interactions take place, are forced to live together (Martin 2001).

6.3.1.2. Hypothesis II: Ecosystems adapt and change

It contemplates the modification of present ecosystems with regard to their composition and the relationships between species, due to differential response of these to the change. The disappearance of certain species or the immigration of new species could lead to cascade reactions in relation to other components of the ecosystems. With our current level of knowledge, this scenario does not allow for accurate predictions in most cases.

6.3.2. Detected changes that might affect the survival of populations

6.3.2.1. Phenological changes

6.3.2.1.1. Phenological changes in vertebrates

Advances or delays in natural processes caused by rapid climatic changes could give rise to responses in the phenology of vertebrate populations. Many vertebrates' prey organisms can respond more rapidly than them to the change, bringing about a loss of synchronisation between consumers and resources. Many vertebrate species respond to seasonal variation in circadian rhythms in order to initiate processes of reproduction, migration or hibernation, and this variation is not affected by climate change. However, the resources upon which they depend may respond to climate conditions, which would cause a loss of synchronisation. One of the most likely consequences of a loss of synchronisation between species at different trophic levels is the maladjustment between food requirements and availability thereof for the species at higher levels, and this could lead to reproductive failure or reduced survival (hypothesis II).

Species with shorter cycles can respond to selection by means of very rapid micro-evolutionary changes. For species with long generation time, response to rapid changes in the availability of resources can only be by means of phenotypic plasticity. The degree of plasticity is modulated by variability in the environmental conditions experienced by species in evolutionary time. Genetic variability can also make adaptation to change by short lived species possible.

- One of the most notable changes detected in amphibians is the advance in reproduction of many species in Europe and North America (Beebee 1995, Gibbs and Breisch 2001). However, there has been no long-term study in Spain capable of detecting these advances. Data have been collected for the last five years for populations of the common frog (*Rana temporaria*, "species of special interest") in low zones (< 600 masl) and high zones (>1600 masl) in the Cordillera Cantábrica mountains (A. G. Nicieza, pers. com.) During this time, reproduction starts in high areas when the snow withdraws from the pools, but this had never happened (even if there is no snow in the area) before the second or third week in March. It would be interesting to obtain information on the genetic and environmental components of the process determining the start of migration towards breeding grounds.

- With regard to phenological changes in birds, we can highlight those observed in reproduction and migration. Research has been done into whether there are advances in the initiation of reproduction attributable to recent climate change on the Peninsula. In the three species studied (Great tit *Parus major*, blue tit *Parus caeruleus* and pied flycatcher *Ficedula hypoleuca*, all "of special interest") no change was noted in the laying date or size of the clutch in the last three decades (Sanz 2002 2003, Sanz *et al*. 2003). This contrasts with what has been observed for the rest of the western palearctic, where these changes have been detected and attributed to recent climate change (Sanz 2002, Sanz 2003). This can be explained by the fact that in the populations studied on the Peninsula, the temperature increase detected in the last few decades occurred in the months following the start of reproduction and not earlier, so effects on reproductive success could therefore be expected (Peñuelas *et al*. 2002, Sanz *et al*. 2003). In the Canary Isles, sporadic cases of reproduction in October and November have been detected in the blue tit.

- There is evidence that the reproductive phenology of several species of Iberian birds is affected by temperature or rainfall before reproduction is initiated. Thus Fargallo and Johnston (1997) have shown that the start of reproduction in a blue tit population in the centre of the peninsula is affected by temperature one month beforehand. With temperature increases at the beginning of spring, these birds advance the laying date. In the Lesser kestrel a relationship has been found between temperature and rainfall in spring and laying date (J. Bustamante, pers. com.). We still have to learn, with the use of long series of data, which are still unavailable, whether the temperature increase detected in the last few decades has affected the reproductive phenology of these birds.

- During the last 18 years, a decrease in reproductive success together with a loss of fledgling condition and lower recruitment levels has been observed in populations of the pied flycatcher in the Sistema Central (Sanz *et al*. 2003). This study was carried out at the southern margin of the distribution of the species in Europe. Given that the Iberian peninsula constitutes the southernmost part of the distribution of many bird species (Martí and del Moral 2003), and that, as a response to climate change, many species may change their distribution towards northern Europe, it is important to study this precisely in these areas. The process may involve the colonisation of new breeding grounds or the extinction of populations in the southern zone. There is evidence to indicate that the reproductive success of many species breeding on the Iberian Peninsula is negatively affected by less rainfall during spring (Carrascal *et al*. 1993, Zuberogoitia 2000, García and Arroyo 2001) or by an increase in temperature (Lucio 1990). However, no study has attempted to see whether these effects, which are to be expected in a scenario of climate change, have occurred in these species in the last few decades.

- With regard to migration, changes have been detected, showing an average delay of 15 days in the arrival of 6 trans-saharan migrating birds during the last 50 years (Hoopoe *Upupa epos*, Common swallow *Hirundo rustica*, Cuckoo *Cuculus canorus*, Common nightingale *Luscinia megarrhynchos*, Quail *Coturnix coturnix* and Common swift *Apus apus*, all of these, except for the quail, “of special interest”). In this study, carried out in a site in Barcelona province (Peñuelas and Filella 2002), it was seen that 5 of the 6 species showed a statistically detectable delay, and in 4 species there was a relationship with temporal changes in temperature, and in one species, there was a relationship with temporal changes in rainfall. This delay in arrival at the breeding grounds on the Peninsula is in contrast with the generalised advance observed in the same period in the phenology of plants and insects (Peñuelas and Filella 2002). This suggests that these species must have a lower reproductive success rate with the passing of time, as a result of the maladjustment between their arrival and the availability of food (hypothesis II). Predators specialised in hunting migratory birds, like Eleonora’s falcaon (*Falco eleonorae*, “of special interest”), could suffer maladjustment between their reproductive cycle and migratory transit.

- It is known that arrival date of the Common swallow in England is related to the mean temperature in March on the Iberian Peninsula (Huin and Sparks 1998). The greater the temperature increases along the migration route, the lager the advance in the date of arrival at the breeding grounds. The Iberian Peninsula being an important area of migratory transit on a continental level, any changes that take place therein can be seen in phenological changes in different species of migratory birds that breed in other regions of the continent. Furthermore, certain species of birds, like the Common stork or the Common swallow, have changed their migratory behaviour. Many individuals of these species spend the winters in the south of the Peninsula, thus avoiding migrating across the Sahara (Ardeola ornithological news). It is not clearly known whether this established fact is due to the increase in mean winter temperatures on the Peninsula or to other causes. The constant presence of food in rubbish dumps probably has a greater effect than temperature.

- Drought conditions delay reproduction in the Deer *Cervus elaphus*, reduce fertility in females and increase the death rate in offspring, especially in males (Clutton-Brock *et al* 1982, Carranza 1999).

6.3.2.1.2. Phenological changes in invertebrates

- Using climatic manipulation in herbaceous habitats, in a community of molluscs in the United Kingdom (Sternberg 2000) it has been shown that the different species of the snail and slug community present different responses, which are mainly seen in their phenology and in their feeding preferences. In conditions of summer drought, the increased litter cover on the soil favoured the species that feed on this (e.g. *Monacha cantiana*) which showed an increase in activity and population, whereas the species that feed on green leaves and tender shoots (e.g. *Candidula intersecta, Deroceras reticulatum*) increased their populations with supplements of rainwater in summer. It can be predicted that the species with an annual life cycle (most Helicidae) will be more sensitive to changes during their growth period. It was also experimentally observed that in *Helix aspersa* a simultaneous increase in CO_2 and temperature leads to an increase in recruitment of juveniles and an acceleration in their emergence (Bezemer and Knight 2001).

- In the Northeast of Spain, it has been observed that, since 1988, the flight period of a large number of butterfly species is starting increasingly earlier, which for some species constitutes a significant advance of between one and seven weeks, with an average of 0.1 weeks/year (Stefanescu *et al* 2003). This process is logical if we consider that the development periods of the immature phases of insects very much depend on temperature (Ratte 1985), and that in most butterflies the end of the diapause and the end of their development coincides with the arrival of spring (a period in which greater temperature increases have also been detected).

- There is evidence that some species of Satyrid and Lycaenid butterflies show very marked responses to climate change, varying greatly in their annual peaks of flight activity (Stefanescu *et al*. 2003).

- In some species of Satyridae a clear advance in the flight period has been demonstrated, like in the case of *Melanargia lachesis*, *Pyronia tithonus*, *Pyronia cecilia*, *Coenonympha pamphilus* and *Lasiommata megera*, all of these with a larval regime associated with grasses (Stefanescu *et al*. 2003).

- The temperature increase is expected to cause an advance in the start of the annual migration of aphids. Many of these species cause plagues in crops, and the factor related to their early arrival in many areas should be taken into account. An advance in the colonisation of crops is expected, occurring at earlier development stages of these plants, which are therefore more sensitive to attack by pests, which could cause either direct damage, or indirect damage through viruses. This could cause an increase in the use of chemical insecticides.

6.3.2.2. Changes in morphology, physiology and behaviour

6.3.2.2.1. Changes in the morphology, physiology and behaviour of vertebrates

One of the possible consequences of temperature increases might be a directional selection in favour of smaller body sizes. According to Bergmann’s rule, in homeothermic vertebrates, warmer climates would favour a smaller body size, due to its greater capacity to eliminate heat. In certain birds in Israel, significant decreases in body size have been detected throughout the last century (Yom-Tov 2001). There is no study of this nature in Spain, although there are collections of specimens from different periods that could be used to this end.

Certain negative effects have been suggested regarding the effects of temperature increases on the embryonic stage of vertebrates. In many species of reptiles, sex is determined by the temperature of the nest. An increase therein could lead to an exaggerated bias of sexes, negatively affecting the capacity of individuals to reproduce (Dawson 1992). In mammals, temperature increases could cause hyperthermia in pregnant females, and the consequent thermal stress on the embryos, which in some species would determine a high death rate of embryos (McLean 1991). These effects of temperature on the viability of embryos have been proposed as a reason for the disappearance of many large mammals after the last glaciation (McLean 1978).

In bats, a bioenergetic model predicts a closely related combination of temperatures in the hibernacle and winter durations in order to allow for successful hibernation. This suggests that the thermal dependence of the hibernation energetics constrains the biogeography of these species (Humphries *et al*. 2002). The model predicts a pronounced spread northwards of hibernnating bats in the next century. No study of hibernation bioenergetics has been made in Spain. Furthermore, the capacity to regulate body temperature and to prevent hyperthermia in their daytime refuges may become limited and lead to direct mortality (M. Delibes, pers. com.).

A general proposal that has been put forward is that ectothermic vertebrates would be more sensitive to abrupt climate changes, given their lower level of autonomy in relation to the thermal environment. In general, adaptation to climate change could derive from micro-evolutionary changes based on underlying genetic variation or on phenotypic plasticity (Dawson 1992). At present, there are no studies in Spain to explore the viability of both routes to adaptation in vertebrates.

- The age structures of several populations of Iberian cyprinid fish species show a greater abundance of old age classes in relation to young ones (Rincón and Lobón-Cerviá 1989, Velasco *et al*. 1990). This indicates that there are frequent inter-annual differences in reproductive success and recruitment. No rigorous study has been made in Spain of the correlations between climatic variables and the reproductive success of cyprinid species, but studies in other countries of a widespread cyprinid which is also characterised by these fluctuations in recruitment suggest that these variations are modulated by temperature, and to a lesser degree, by rainfall, during the first stages of development (Lobón-Cerviá *et al*. 1996).

- In the Pied flycatcher negative tendencies have been detected in energy expenditure (reproductive effort) or in provisioning rate during the last few decades in populations studied in the *Sistema Central* (Sanz *et al*. 2003). These insect-eating birds suffer maladjustment with their main prey (caterpillars), due to recent climate change, and they have varied the prey that they take back to the nest for their young (hypothesis II). Changes in the physical condition of males and females were observed (Sanz *et al*. 2003). The daily energy expenditure, an integrated measurement of the reproductive effort of these birds, has dropped in recent years, mainly due to its negative relationship to environmental temperature (Sanz *et al*. 2003). These changes in synchronisation with their prey (caterpillars) due to recent climate change probably accounts for the changes observed in adult metabolism, reproductive effort and reproductive success (see above).

- There is also evidence that rainfall in spring affects the condition and growth of the chicks of nesting birds (Carbonell *et al*. 2003). With less rainfall, the condition and growth of the chicks of Blackcaps (*Sylvia atricapilla*, “of special interest”), measured by means of fluctuating asymmetry and feather growth, are impaired (Carbonell *et al*. 2003). This indicates that we can predict effects on the growth of these birds in a scenario of climate change.

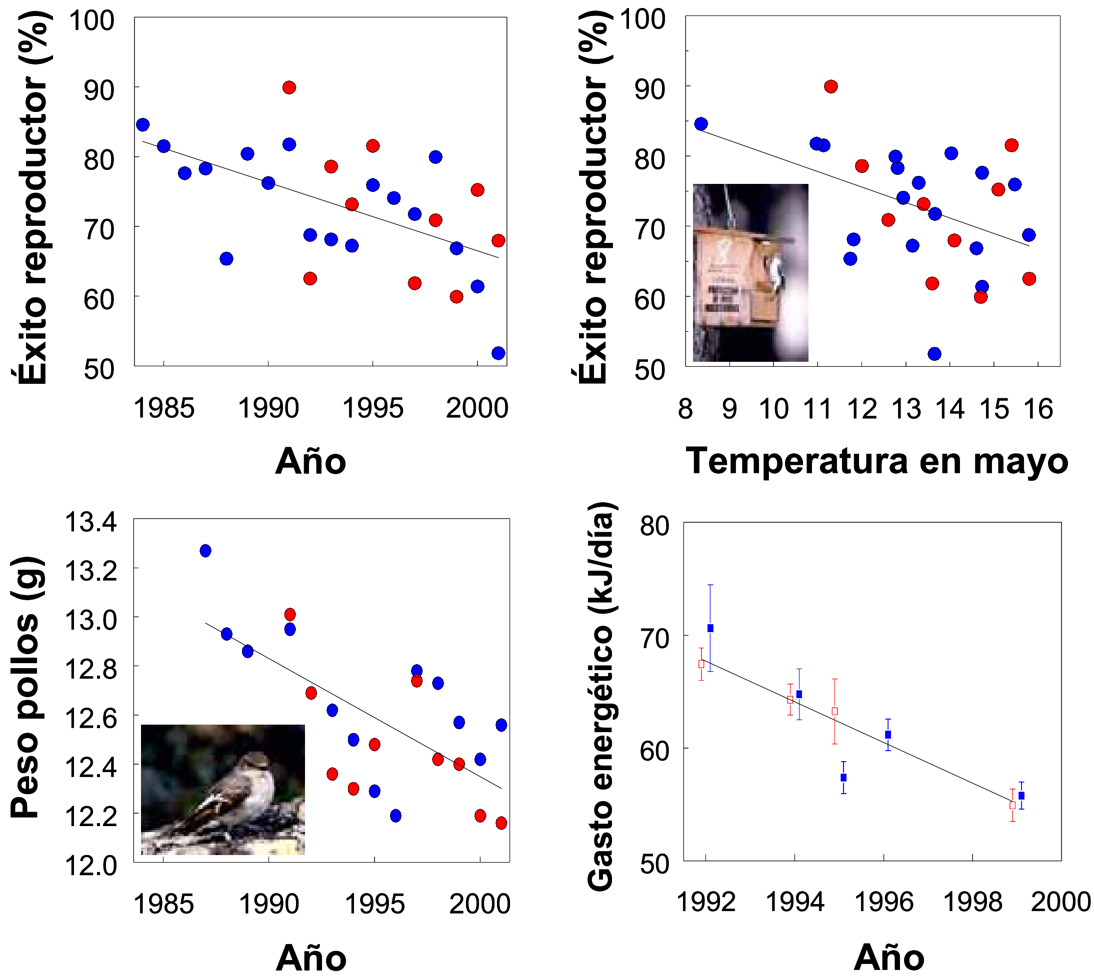

__Fig. 6.4.__ Temporal changes over more than one decade in the reproductive success of two populations of pied flycatcher in the Sistema Central (blue dots: La Hiruela, Madrid; red dots: Valsaín, Segovia) and in the daily energy expenditure of adults during the end of the nestling stage(blue symbols: females, red symbols: males) fom Sanz et al. 2003).

- In the Lesser kestrel, a bioclimatic model indicates that reproductive success is positively affected by rainfall. However, despite the fact that rainfall has decreased significantly since 1966 in the study area, a retrospective analysis of the evolution of the size of several colonies in Andalucia indicates that the effect of climate change on reproductive success cannot be responsible for the historic population decline (Rodríguez and Bustamante 2003).

6.3.2.2.2. Changes in the morphology, physiology and behaviour of invertebrates

- A similar effect to the Bergmann's rule, previously mentioned for vertebrates, has also been observed in molluscs. In the gastropod *Capaea nemoralis* a direct correlation has been described between the diameter of the shell (standard size measurement) and altitude in three valleys in the Spanish Pyrenees (Ramos 1981). That is, size increases in populations at greater altitudes where temperature is lower.

- On some occasions, experimental results in relation to terrestrial gastropods are contradictory. Thus, the consumption of food in the juveniles of *Helix pomatia* increased in environments with high levels of CO_2 (Ledergeber *et al*. 1998), whereas in another experiment with *Helix aspersa* consumption was not affected by CO_2 concentration (Diaz *et al*. 1998). The different response of the two species could be due to intrinsic physiological differences. In any case, these results suggest that predictions cannot be based on the variation of one single factor (temperature, humidity or CO_2 concentration), and that there is a need for the combined study of the different environmental factors that can vary synergically as a consequence of climate change in natural conditions, and we should also keep in mind microclimatic factors, the evolutionary history of the animal group and the physiological characteristics of the species.

- Both in natural (Potts 1995; Chevalier 1980 1992) and experimental conditions (Iglesias *et al*. 1996), a latitudinal gradient has been observed in the life cycle of *Helix aspersa.* The length of the hibernation period decreases with latitude, from seven months in Scotland to four months in the Northwest of Spain. In Atlantic areas of Galicia, the species has a long hibernation period without aestivation and reproduces during summer, whereas in the other part of Galicia, with a Mediterranean climate, there is both hibernation and estivation and reproduction takes place in spring and autumn (Iglesias *et al*. 1996). Reproduction in autumn is typical in all Helicidae gastropods in the Mediterranean area, although the survival rate of the autumn offspring is much lower due to wintertime cold than in those reproducing in springtime. Furthermore, both in *H. aspersa*, and in *H. pomatia* and *H. texta* rainfall appears to be the determinant factor in species activity in Mediterranean areas (the exit from hibernation is related to rainy periods and entry into aestivation to the start of the dry periods), whereas photoperiod might be more important at high latitudes. In any case, this latitudinal cline is conditioned by the microclimatic factors affecting the population, which can make it deviate from the general pattern.

- The longevity of the individuals of the species *Margaritifera margaritifera* varies with latitude. Thus, whereas the average life span of specimens in Spain is around 70 years, this can reach up to 200 years in Scandinavia and on the Kola Peninsula (Araujo, personal communication). In this case, water temperature may be an important factor.

- The population dynamics of species of terrestrial arthropods is conditioned to a great extent by the environmental conditions of temperature and humidity. The movement observed towards the northern limit of the distribution area of insect species should be interpreted as a response to an increase in mean annual temperature. Temperature increases also cause greater variability in rainfall periods, in the intensity of these and in evapotranspiration rates (Piñol *et al*. 1998). The significant changes taking place in the amount and seasonal distribution of rainfall may have negative effects on population viability, with a higher risk of extinction (McLaughlin *et al*. 2002). In order to demonstrate this hypothesis, research would be needed that took into consideration several orders of insects in which species with well-known distribution and biology are selected.

- Furthermore, we are aware of the existence of groups of insects, capable of regulating their internal flight temperature, and which present activity during the cooler times of day, like dusk or the early hours of the night (Heinrich 1993). These groups have well-developed muscle masses, a high wing loading and their capacity for flight depends on the balance they establish between the generation of body heat and its loss by means of external diffusion into the surrounding atmosphere. These insects behave like endothermic ones during flight, and have the capacity for thermoregulation, but when they are not flying, they are poikilothermic. . An increase in temperature could seriously affect these species among which we find lepidoptera like the Sphingidae, and pollinating insects like many hymenopteran Apoidea and coleopteran Scarabaeidae. Many of these species have a very restricted distribution in Western Europe, or are Iberian endemisms, and also have a low reproductive rate (Verdú *et al* 2004a).

- The changes observed in some lepidoptera in relation to the advance in their flight period, could indicate that some insects have a type of response that enables them to adapt to the new climatic conditions of global warming. This response is not a generalised one, however, and our available data are very scarce and geographically local. There is a need for long annual series showing the abundance of the populations affected; the historic fauna records are scant and poor, due to a great extent to the lack of support for this type of studies from Spanish scientific policymakers.

- The changes that may occur in the phenology of the appearance of adults in insects and larval development periods could have serious consequences in the near future with regard to changes in population abundance resulting from the possible desynchronisation in the phenology of nutrient plants and insects. In the Mediterranean basin, many species of rhopalocera butterflies lay their eggs at the end of spring or the beginning of summer, and enter into a state of calm or aestivation that may last the whole winter, thus avoiding the more environmentally unfavourable periods. An advance in the period of emergence of adults causes an advance in the clutch period and birth of the larvae, which could represent a critical lengthening of the aestivation period with fatal consequences for the survival of the first larval stages (Stefanescu *et al*. 2003).

6.3.2.3. Changes in geographic distribution:

6.3.2.3.1. Changes in latitudinal or altitudinal geographic distribution in vertebrates:

The prediction of displacements towards the north or in altitude of species affected by climate change (hypothesis I) is based on the capacity for migration of the individuals towards more favourable habitats (Root and Schneider 2002). It must be pointed out that this capacity differs among groups of vertebrates. Whereas birds can fly over different types of barriers, amphibians and reptiles have much less capacity for migration, and mammals are in an intermediate situation. Besides, several human factors restrict this capacity, especially in Europe. The main factor in this sense is surely the increasing fragmentation of habitats. Terrestrial environments are interrupted by increasingly larger areas of infrastructures and urban environments, while river environments are fenced in more and more by reservoirs. Spain has become modernised in its transport infrastructures and has adopted the town planning model of large suburban areas far from the city centres. Habitat fragmentation is one of the prices of economic development and of the adoption of the new town planning models. Furthermore, Spain is one of the countries in the world with most reservoirs per inhabitant, which does not seem to imply any decline in the construction of new ones. As a result of all this, the tremendous and growing fragmentation of natural habitats does not only impede the geographic displacement of distributions according to climate (hypothesis I), but probably even any genetic exchange needed to guarantee the viability of many fragmented populations in a scenario of no climate change (a paradigmatic example is the Iberian Lynx *Lynx pardina*). In island ecosystems on the Canary Isles, the species cannot respond in the same way as those on the continent, which move northwards, and their potential capacity for response would be restricted to changes in altitude, and only on islands with high elevations (for instance, the central and western islands of the Canaries: Gran Canaria, Tenerife, La Gomera, La Palma and El Hierro). This type of movement would be much more limited on the eastern islands, Lanzarote and Fuerteventura.

Certain species have a reduced possibility to react by means of changes in distribution. These are the ones living in high mountain areas and the island populations. They have literally nowhere to go. In Spain, the barriers constituted by several mountain ranges running from west to east prevent northward displacements of some species. Those species highly specialised with regard to certain climatic conditions would also be more sensitive.

The simplistic model that predicts that plants will respond to climate and that animals will follow the plants (hypothesis I) does not take into consideration that animals may respond directly to climate in order to avoid physiological limitations (Dawson 1992) and may change habitats regardless of vegetation. This could involve changes in biotic interactions, with effects on survival and reproduction.

- With the exception of northern Portugal, the rivers in Cantabria constitute the southern limit of the distribution area of the Atlantic Salmon in Europe. Survival during the embryonic and post-embryonic stages (previous to exit from the gravel pits) is closely related to temperature. An increase of 3-4 º C above optimum for survival leads to a drastic increase in death rate and the proportion of deformed unviable individuals (A. G. Nicieza, pers. com.). The same can be applied to the lamprey or the trout (Ojanguren 2000, Rodríguez-Muñoz 2000). A continuous or maintained increase in water temperature during the winter and spring months could contribute to population decline and to the displacement towards the north of distribution limits.

- In general terms, and despite the lack of studies aimed at determining the effect of climate change on populations of amphibians, the biogeographic islands represented by the mountains (and certain areas with higher rainfall) in the centre and south of the Peninsula are ceasing to serve as efficient refuges for the fauna of more northern distribution, and the endemisms of these areas, like the Iberian midwife toad (*Alytes cisternasii*, "of special interest") and the southern subspecies of Common midwife toad (*Alytes obstetricans,* "of special interest") and Salamander *Salamandra salamandra* are seriously threatened (R. Márquez, pers. com.). Thus, local populations of salamander have disappeared in Sierra de la Demanda and Neila (Burgos, although here, the introduction of salmonids may be an alternative or additional factor), Colomerá and El Padul (Sierra Nevada, Granada) and Puerto y Llanos de Zafarralla (Granada) and of the Alpine newt (*Triturus alpestris*, "of special interest") in Carrales and Pantano del Ebro (Burgos) (Pleguezuelos *et al*. 2002). Reductions of salamander populations have been detected in Sierra de las Nieves (Málaga), Sierra Bermeja and Serranía de Ronda (Málaga) and in the Sierra de Córdoba, of the Alpine newt in Northern Castilla-León, Cantabria and Álava and of the Iberian frog (*Rana iberica*, "of special interest") in Peñalara (Sierra de Guadarrama, Madrid) and in Las Villuercas, Guadalupe and Valencia de Álcantara (Extremadura) (Pleguezuelos *et al*. 2002).

- There have been recent observations of low-altitude species in high-mountain habitats in the centre of the Peninsula, which were previously the exclusive refuge of species of more northern distribution (hypothesis I). Thus, in the Laguna Grande de Gredos (Ávila) the Common Frog *Rana perezi* has only been sighted in recent decades, and the Common tree frog (*Hyla arborea*, "of special interest") can currently be found in some of the alpine lakes of the Somiedo Nature Park (Asturias) (R. Márquez, pers. com.).

- From the 50s to the 80s of last century, a change in the distribution of the Algerian sand lizard (*Psammodromus algirus*, "of special interest") was detected in a valley of the Pyrenees (hypothesis I), and its presence was recorded 30 km upriver from where it had initially been seen (Bauwens *et al*. 1986).

- In this context we must mention reptiles typical of mountain habitats with a distribution very much associated with climate. Climate change would cause their rise in altitude and their disappearance at low elevations (hypothesis I). One example is Schreiber's green lizard, an Iberian endemic species which, in the Mediterranean area is associated with mountains and in the Southern half is now found in more humid and cooler available habitats (Marco and Pollo 1993, Brito *et al*. 1996). Climate change is threatening populations in the Montes de Toledo, Sierra de Guadalupe, Sierra de Monchique, etc., because these cannot rise any higher and are losing ideal low-altitude habitats, and it is very likely that this species has become extinct in the last few decades in Sierra Morena. There are very old references to the Lizard in the Sierra de Andújar and some sightings in the 1980s, but in the last intensive sampling sessions, it was not seen again in these places. In Andalucia, it is classified as threatened, precisely due to these references from the 80s (Marco 2002). In a similar situation appears to be the Spanish Algyroides (*Algyroides marchii*, "of special interest"), the Viviparous lizard (*Lacerta vivipara*, "of special interest"), the Pyrenean rock lizard (*Lacerta bonnali*, "vulnerable"), the European smooth snake (*Coronella austriaca*, "of special interest") and the Iberian rock lizard *Lacerta monticola*.

- GIS distribution models extrapolated to increases of 2-3 º C up to 2080 predict a reduction of the distribution area of the Long-tailed salamander (*Chioglossa lusitanica*, "of special interest") by 20% (Teixeira and Arntzen 2002);

- On the Iberian Peninsula, changes may occur in the distributions of birds, given that current distribution and abundance patterns can be accounted for, along with other factors, by climatic variables (Carrascal and Lobo 2003). Potential changes in temperature and rainfall regimes must affect the distribution of these species, but no temporal study has been carried out on the Peninsula aimed at contrasting this hypothesis.

- In the case of the Great bustard (*Otis tarda*, "of special interest"), the ecological niche was modelled using 23 points of occurrence in Europe and twelve climatic and topographic covers (Papes personal communication). The prediction of the present distribution was subsequently intersected with the land use GIS covers, in order to only retain those areas most convenient for the Great bustard. Likewise, the ecological niche model was projected in the two scenarios of climate change and the average of the two was intersected with the current distribution, assuming zero capacity of the species to disperse. Figure 6.5 shows that the southern part of the current potential distribution of the Great bustard will disappear with the future climatic conditions.

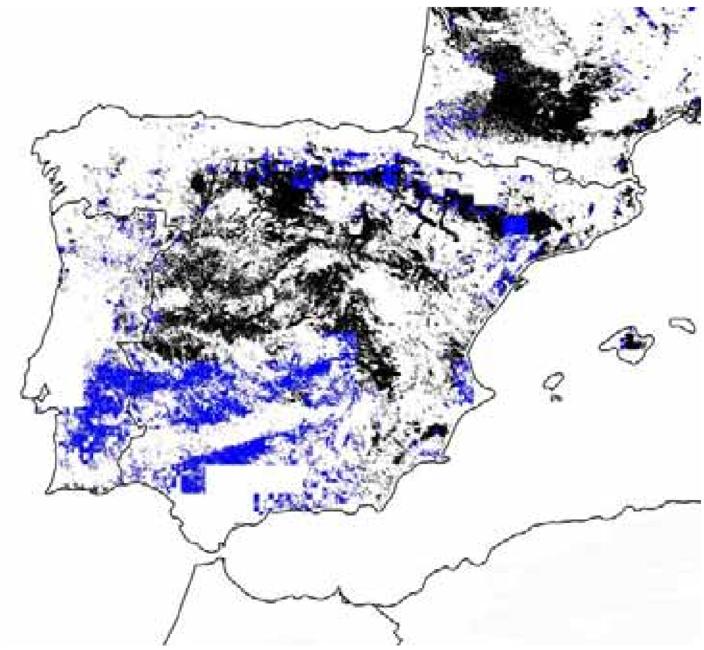

Fig. 6.5. *Modelling of the effects of climatic change on the potential distribution of the Great bustard (*Otis tarda*), a threatened species. The black-grey tones show the areas with the right conditions for the species at present, whereas the blue tones indicate the areas that will be reduced in the future*

- In the case of the Capercaillie (*Tetrao urogallus cantabricus*, “vulnerable”) in the Cordillera Cantábrica, the display sites or leks abandoned recently are at lower altitudes than those still occupied by capercaillies (Obeso and Bañuelos 2004).

6.3.2.3.2. Changes in latitudinal or altitudinal geographic distribution or zoning in Invertebrates:

- As was mentioned in section 2.2, we cannot expect the communities of terrestrial molluscs, or the majority of unspecialised edaphic invertebrates (i.e. mites, nematodes, etc.), to be seriously affected by the direct effects of climate changes. The most limiting factor is humidity (Subías personal communication), whereas temperature changes could have a long-term effect due to the buffering effect of the soils, provided plant cover is maintained. Only a drastic alteration of the ecosystem, such as erosion, could have serious consequences. An irreversible latitudinal and/or altitudinal displacement of plant communities could cause modifications in the species composition of the malacofauna, and other edaphic communities, although this will differ depending on whether we are dealing with herbaceous, xerophilous habitats, or different types of forests.

- In the case of rivers, reduced flow and warming of the waters could cause the intrusion of the fauna from mid-mountain to high mountain areas, as well as habitat fragmentation. In the first case, there would be a displacement of the biocenosis upstream (Hypothesis I) (see Chapter 3), provided that other factors, such as substrate type of current speed do not limit the survival of thermophilous species, and at the same time, the populations of cold water species could be reduced and, in some cases, totally disappear. Fragmentation appears to be the case of trout and salmon rivers, in which the decrease, already evident, of these fish species would be accentuated. This would have very negative consequences for the highly threatened species of large bivalves.

- Altitude, latitude and depth seem to play the same role on the distribution and diversity of the malacocenosis (gastropods and bivalves) in 43 European lakes (Mouthon 1990). The stations with the greatest species richness correspond to the littoral zones of medium to low altitude lakes, and is greater towards the South. The littoral areas of mountain lakes and the deep parts of all lakes are the places poorest in species. This distribution suggests that temperature (and the associated climatic conditions) is the main factor associated with species distribution and abundance. That is, unless a temperature rise, increased drought, eutrophication by pollutants or desiccation of aquifers cause the disappearance of permanent lakes and lagoons, or irreversibly alter them, the predicted change may not affect, or even have a positive effect on the freshwater malacofaunas therein. This may even have a positive influence upon the following links in the trophic chain. The mollusc species inhabiting these environments, however, belong to more generalist and tolerant groups, in which endemisms are rare.

The available data on insects indicate that alterations may occur in the ecosystems and show the extent of damage caused by invasive species of medical-veterinarian importance and with regard to crop plagues.

- Analysis of the whole distribution area in Europe of 35 species of butterflies, showed that 63% of them had spread to latitudes further north of their distribution area, whereas 6% had spread southwards and 3% had done so in both directions (Parmesan *et al*. 1999).

- In the 70s of last century, of a total of 38 species of non-migratory butterflies living in Great Britain, it was found that 47% of the species had spread their distribution area northwards, whereas only 8% had done so towards the south (Parmesan *et al*. 1999). The magnitude of movement of the distribution area towards Northern Europe of some butterflies is, depending on species, between 35 and 240 km, which cannot simply be attributed to the mere spread of the species, as it significantly surpasses the distances of natural colonisation processes of any of the species considered in this study (Parmesan *et al*. 1999).

- On analysing the distribution of 40 species of butterflies (France, Spain, Morocco, Tunisia and Algeria), a northward displacement was observed in the southern limit of distribution in 22% of the species and a southward spread in distribution in 5%, the rest remaining invariable (Parmesan *et al*. 1999).

- It has been observed that the southern distribution limit either remains stable in most of the species studied (approximately 65%) or a small displacement towards the north of this southern limit is observed (in approximately 35%).

- *Heodes tityrus* (Lepidoptera Lycaenidae), a species whose southern distribution limit was in Catalonia, has changed its range of distribution. It was an abundant species in Montseny (Barcelona) throughout the last century, but it disappeared at the end of of the 1990s due to causes that cannot be attributed to habitat alteration. At the same time it has been seen that in Estonia, where sightings were sporadic throughout the last century, it has established permanent breeding grounds (Parmesan *et al*. 1999).

- In order to evaluate the possible consequences of climate change on many endemic species of the Iberian Peninsula, we must remember that we are in an interglacial period which began around 10,000 years ago, and during which the strips of vegetation and the associated insects were gradually displaced northwards. It is important to keep in mind that in many insect species, the populations isolated on mountain tops, and therefore without any genetic exchange, are the result of a previous colonisation process during cold periods, when population continuity existed, and that they are real glacial relicts of past times. In these cases, although they have not given rise to new species during recent history, they have generated numerous subspecies differentiations, as has happened, for example, with *Parnassius apollo* (Lepidoptera Papilionidae), whose populations are found at the highest elevations on the different Spanish mountain ranges. Species like the aforementioned one do not have any possibility to make south-north migrations due to the transversal (latitudinal) arrangement of the mountain ranges, and are restricted to small areas with the sole possibility of emigrating towards higher elevations, if this possibility were, in fact, to exist.

- In other cases, the consequence of the glacial period was a drastic reduction of geographic distribution areas, so that many species were confined to authentic Iberian Pleistocene refuges, as no subsequent recovery of their primitive distribution area has taken place. In this way, species that had long been considered endemic of a certain area, are the remaining legacy of an abundant and widely distributed population from before the last glaciation, the geographic distribution area they currently occupy constituting their last refuge (Elias 1994). Thus, in Spain we found insect species that are real evidence of past times and which are currently confined to enclaves in Mediterranean Europe, like A*phodius bonvouloiri* (Coleoptera Aphodiidae), a coprophagous species very abundant in the pastures of the mountains of the Sistema Central and the Cordillera Cantábrica and which we know lived in Great Britain during the warm periods half-way through the last glaciation, where it was associated with other species of insects typical of more temperate climates (Coope and Angus 1975). Likewise, during the last interglacial period, many species of coprophagous scarabaeid coleoptera (dung beetles) now considered as typical of the Mediterranean regions in southern Europe, like *Onthophagus furcatus* or *Euoniticellus fulvus* existed in Great Britain in the preglacial period (Coope 1990). Many other examples have been found among the coleoptera because of the greater ease with which they leave subfossil deposits, which is why we know that some species of carabids whose present distribution area covers part of the Iberian Peninsula and the South of France must have existed in much of Europe before the last glacial period (Coope 1990). All these groups of insects can be expected to be seriously affected by global warming.

- Although the species of migrating insects may be able to respond to a great extent to climate change by means of variation and adjustment of their annual displacement periods in accordance with new environmental conditions, most arthropods are sedentary, and displacements are within a radius of, at the most, a few hundred metres. For sedentary species, response to climate change will involve changes in the northern and southern limits of their distribution areas. This will inevitably lead to changes in their population levels, causing variations in the relationship between extinction and colonisation to the north and south of the species' distribution range.

6.3.2.4.Changes in ecological interactions

6.3.2.4.1. Changes in ecological interactions in Vertebrates

There are two possible effects of climate change on vertebrate populations that are of increasing concern to specialists. One is the possibility that more benign climatic conditions will favour displacements towards our latitudes of parasite vectors or of the parasites themselves (Rogers and Randolph 2000, Patz *et al*. 2000). The interaction between the effects of changes in temperature and rainfall is crucial in this sense. The conditions of temperature increases accompanied by reduced rainfall do not necessarily favour parasitosis. Thus, for example, the incidence of the viral haemorrhagic epidemic in rabbits appears to be less virulent, at both local and regional scale on the Iberian Peninsula, in the dry areas than in the wetlands, perhaps because there are more vectors in more humid conditions (M. Delibes, pers. com.). In relation to this problem, it is possible that the virulence of existing parasites may be favoured by the immunodepression of the hosts caused by environmental change. The spectacular global decline of amphibians detected in the last few decades seems to be associated, among other factors, with infections in eggs, larvae or adults by parasites, especially fungi (Blaustein and Kiesecker 2002). In some cases, this could be related to immunodepression in the hosts. To what extent climatic conditions favour the spread of parasites (hypothesis II) still remains to be seen.

The other problem associated with climate change could involve the spread of introduced species due to more favourable climatic conditions. For example, the introduction of foreign species of fish in our rivers for sports fishing is a problem for the conservation of our autochthonous fish, regardless of climate change (Doadrio 2001, Elvira and Almodóvar 2001). If this increase were also to be favoured by the aforementioned climate change, the problem would get worse (Elvira 2001). Many examples can be given of the dramatic effects on biodiversity of species introductions (turtles, parrots, etc.). However, other introduced species could be negatively affected by the foreseeable climate changes (for example, the American mink). The introduction of exotic species or varieties favoured by climatic change could lead to crossbreeding and the loss of endemic genetic diversity on the Peninsula. In the Canary Isles, this type of species, especially parrots, are spreading rapidly, favoured by their commercial value and by irresponsible practice of zoological nuclei ("escapes") for tourism, which are subjected to no control by the public authorities. This has led to a marked transformation of the urban fauna in the last 20 years. However, we must consider that in the Canaries there are forest of great scientific interest, the subtropical laurel forests that occupied the Mediterranean basin in the Tertiary. This subtropical feature might be optimum for certain species of parrot which are being introduced, while these relictic forests harbour two species of endemic pigeons, Bolle's Laurel pigeon (*Columba bollii*) and the Laurel pigeon (*Columba junoniae*, "sensitive to habitat alteration") (Martín *et al*. 2000), which could be negatively affected.

- A collapse has been detected in populations of Common midwife toad due to infection by fungi, through the possible involvement of climate change (Bosch *et al*. 2001).

- We know that, with an increase in temperature during springtime in the Sierra de Ayllón (Madrid), the number of nests of pied flycatchers attacked by ectoparasites has increased (Merino and Potti 1996). In a scenario of temperature increase and/or reduced rainfall, some nesting birds in our latitudes may be expected to show a drastic reduction in reproductive success due to infestation of their nests by ectoparasites.

6.3.2.4.2. Changes in ecological interactions in Invertebrates:

- Fluctuations in temperature and humidity and changes in land uses directly affect edpahic fauna in the long term. This is often more conditioned by the effects of indirect climate changes and CO_2 increases on the vegetation (in herbivorous species), nutrient availability and effects on the soil itself. It seems that these direct and indirect effects could have a cascade effect on herbivorous and decomposing organisms. The lack of good taxonomies hinders research into these processes, which tends to be based on experimental models. One hypothesis suggests that there is considerable species redundancy within each functional group, although changes in the diversity of functional groups could have serious consequences for the processes of ecosystems. Given the great diversity and adaptability of soil organisms, these ecological concepts suggest that redundancy and/or substitution are frequent in edaphic systems. One possible consequence is that the impact of environmental changes might be less than what was expected from the extrapolation of the results of studies to isolated organisms. To the contrary, bigger impacts that modify the bidiversity threshold, with gains or losses in a given functional group, such as earthworms or termites, could have a significant effect upon edaphic processes. While these alterations are more likely due to changes in land uses and pollution, which lead to displacements of the vegetation, the differential capacity of soil organisms to migrate could lead to changes in the functional composition of edaphic communities (Ingram and Wall 1998, Swift *et al*. 1998).

- Climate scenarios like the one expected for Spain include hotter and drier summers followed by warm winters and more rainfall, which would create the ideal environment for a reduction of the carbon available in the shallower layers of the soil. Given the direct relationship between organic carbon and the structural stability of the soil, the likelihood of erosion increases with a decrease in organic carbon, with the consequent impact and impoverishment of the fauna. This effect would be greater in Mediterranean ecosystems.

- Alterations in the annual period of activity do not affect all groups and species of insects in the same way, which could therefore lead to a serious maladjustment in the necessary synchronisation of the periods of activity of host and parasitoid insects (Hassell *et al*. 1993).

- Likewise, global warming allows for the spread in altitude of species of phytophagous insects that cause plagues, possibly affecting new plant species and relictic forest formations in the south of the Iberian Peninsula. We found an example of this in the altitudinal penetration in Sierra Nevada of *Traumatocampa pityocampa*, a lepidopteran that can cause serious damage to the pines *Pinus nigra*, *P. halepensis* and that seriously affects *P. sylvestris* in the populations situated at lower altitudes. In Sierra Nevada and Sierra de Baza the southernmost populations of Scots pine considered as the subspecies *P. sylvestris nevadensis* are found. Global climate change could very seriously affect this Iberian endemism as a consequence of the altitudinal rise of *T. pityocampa*, given that an increase in the population levels of caterpillars of this species causes a high level of defoliation that reduces the growth rate of *P. sylvestris* by up to 50%, with the consequent reduction of seed production and renovation rate (Hódar *et al*. 2003)

- Furthermore, in groups like the aphids, an increase in mean annual temperature can cause an advance in emigration periods and the early appearance of pests at a time when the crops are most vulnerable (EXAMINE, Victoria Seco pers. com.).

6.3.2.5. Changes in area and quality of potential habitats (degradation, loss, fragmentation, colonisation by invasive species)

6.3.2.5.1. Changes in area and quality of potential habitats for vertebrates

Climate change can determine changes in the availability of favourable habitats for many species of vertebrates. For instance, droughts and longer periods of intense heat can be expected to determine faster desiccation of ponds, wetlands and temporary water courses in spring. For amphibians and fish, this could lead to the extinction of populations of greater genetic isolation (Márquez and Lizana 2002). Some mammals that are widely distributed throughout the Iberian Peninsula, like water shrews of the *Neomys* genus, the water rat *Arvicola sapidus* or the Cabrera Vole *Microtus cabrerae*, could be seriously affected by this problem. The Cabrera vole, endemic of the Peninsula, depends on small masses or bodies of water where it does not compete so much with the water rat, and its populations are therefore very fragmented and vulnerable to prolonged drought (M. Delibes, pers. com.).

Forest fires also cause the loss of forest habitats, as well as the desiccation and sediment accrual in ponds and water points. The forest vertebrate fauna may suffer even greater fragmentation of their habitats and amphibian and fish populations may be reduced even more by a higher incidence of forest fires (see chapter ¿?) due to climate change.

The high temperatures may lead to a proliferation of aquatic plants like, for example, the tropical fern of the genus *Azolla* recently detected in Doñana (García Murillo, pers. com.), which imply anoxia in lagoons and water-courses, with negative effects for freshwater fish. The impacts of these changes (hypothesis II) are still to be studied in Spain. In aquatic ecosystems, the high temperatures would also lead to an increase in the concentration of nutrients with a greater risk of eutrophication (hypoxia, proliferation of algae and toxic bacteria) and also to an increase in the concentration of many types of low-volatility pollutants (the very volatile ones might be less soluble at higher temperatures) (see chapter ?).

The predictable increase in sea level could seriously affect coastal habitats. In important areas for vertebrate species like the Doñana National Park, the increased salinity could have a very grave impact on many species.

- A loss of viability has been detected in the eggs of three species of amphibians (Common toad *Bufo bufo*, Iberian spadefoot *Pelobates cultripes* and Common frog *Rana perezi*, these two "of special interest") in central Spain, due to natural levels of UVB radiation (Lizana and Pedraza 1998, Marco and Lizana 2002, Marco *et al*. 2002). The incidence of these radiation levels may be related to climate if decreased springtime rainfall reduces the level of water in ponds and water courses, because the eggs of amphibians would probably be exposed to dangerous levels of UVB radiation due to a lower protective volume of water. This effect would be less serious for amphibians that lay their eggs on the surface. Thus the Common frog usually lays its eggs on the shores, perhaps to make use of thermal radiation in order to speed up development, so that, even if there is a large layer of water, they lay their eggs in shallow waters. They apparently avoid deep ponds or the deeper parts of these, and the greatest concentration of clutches is always found in the shallow areas, with large masses of eggs "flowering" on the surface. The Common frog, when it breeds in reservoirs, mountain lakes or lagoons, normally lays eggs on the shores or in the water, but in this case, the eggs usually remain on the shallower layers (A. G. Nicieza, pers. com.).

- In the Canaries, there is a serious problem with the population of Blue chaffinch living on Gran Canaria (*Fringilla teydea polatzeki*, “in danger of extinction”), as it is only present in the *montes* of Pajonales, Ojeda and Inagua, and its population has been estimated at around 200 individuals (Rodríguez and Moreno 1996). These pine forests are a geographic unit of *Pinus canariensis*, of around 3.700 Ha, in the West of the island. A big fire would not totally destroy this forest, as the Canary pine is quite resistant to fire, probably as a result of its evolution in volcanic terrain, but the habitat would undoubtedly be seriously impoverished, which would negatively affect the survival of this endemic subspecies.

6.3.2.5.2. Changes in area and quality of potential habitats for Invertebrates:

Alteration of habitat will be one of the determining factors either of the disappearance of species or of their displacement. Many species of insects with aquatic larval phases, such as Odonata, Trichoptera, Plecoptera, Ephemeroptera, Coleoptera, Hemiptera among others, would be affected by the disappearance of pools, humid areas and water courses caused by an increase in drought periods and in mean annual temperatures.

Likewise, given the interaction between many insect species and vegetation, the disappearance of plant species or a change in their area of distribution would seriously affect many species of invertebrates.

- In the upper Tajo region, a bioclimatic area has been described which is differentiated from the neighbouring ones, with elements of flora and invertebrate fauna (molluscs, carabid beetles, isopods) of a central European nature (Ramos 1985, Serrano 1984). This is an area with conditions of marginality and the associated evolutionary phenomena, in several species of molluscs (e.g. *Cepaea nemoralis*, *C. hortensis*) (Ramos and Aparicio 1984). This area could disappear as a result of the loss of the associated deciduous forest, or might be displaced northwards. The latter hypothesis seems unlikely because of the influence of microclimatic factors, which would disappear towards the desertified area of the Ebro basin.

One of the effects of climate change, particularly in the Mediterranean area, is the risk of fire (see chapter 11). The effects of fire have been studied in mollusc communities in the Mediterranean region. The results show that the communities appear to be highly resistant to fire, and to other types of anthropic alterations, provided that the alteration is not maintained for several years and that there is sufficient time between two alterations to recover (see review in Kiss *et al*. 2004). The response patterns to fire appear to be multifactorial. The composition of the present communities of terrestrial molluscs is not only the result of a long history of recurring fires since the Neolithic, but also of other anthropic alterations, of changes in the landscape over centuries, of the structure of the habitat previous to the fire and of the influence of a biogeographic gradient (Kiss *et al*. 2004). It should be mentioned that the Helicidae family (the most numerous with regard to species) has undergone a particular diversification in the Mediterranean Basin. The response pattern obtained may be due to the existence of cryptic refuges in the burnt areas, which would allow for the survival and conservation of the malacofauna following successive fire episodes. This hypothesis is reinforced by the fact that, after fire episodes, the malacofaunas recover and even maintain the proportion of their central European elements in the populations most distant from the Mediterranean sea. This pattern is similar to what has been observed in other components of edaphic fauna, such as in the case of Oribatid mites (Subías, personal communication). 15-20 years after the fire, an almost total recovery of the oribatids community was observed, probably due to the existence of microclimates of refuge areas that have conserved their faunistic elements, thus allowing for re-colonisation.

A unique ecosystem is constituted by springs and small streams. These are habitats with cold and well-oxygenated waters and with a continuous current throughout the year which is not too intense. Due to the mountainous nature of the Peninsula, these habitats are numerous and diverse. They are rich in invertebrates and endemisms, as they are frequently isolated, or only communicatethrough the phreatic waters by which they are fed. These habitats are therefore very fragile, fragmented and sensitive, both to natural desiccation processes and to direct and indirect human activity. The accumulation of wastes, the spillage of pollutant elements and alteration (resulting from activities that cause desiccation or reductions of the phreatic level) are the most common cause of the extinction of the invertebrate populations inhabiting therein. Water scarcity resulting from long periods of summer drought and rises in mean annual temperature, predicted for Spain's Mediterranean area, will exacerbate the problem, either through actions affecting aquifers or greater human intervention, with the consequent irreversible disappearance of these habitats.

- The fauna of these ecosystems remains quite unexplored. Data on the freshwater mollusc family Hydrobiidae indicate that most European species occur in the circum-Mediterranean, area, with the highest species number around three centres of differentiation: the Balkans, Italian and Iberian peninsulas. Numerous genera and new species are being described on the Peninsula (Ramos and col. 2000, Arconada and Ramos 2001 2002 2003). Approximately 90% of the species are endemic, probably due to ancient processes of geographic isolation and to their poor dispersal capacity. The systematic study of hidrobiids molluscs, over the last ten years has indicated the disappearance of some populations and species due to the desiccation of their habitats, even previous to their being described (Arconada and Ramos 2003, in press).

Invasive species constitute an important element of global change and a serious threat to biodiversity. Three species of invasive freshwater molluscs are known in Spain: the gastropod *Potamopyrgus antipodarum* (a native of Australia), and the bivalves *Corbicula fluminea* and *Dreissena polymorpha* from Asia and the Caspian Sea, respectively. The latter two have a huge potential for invasion (based on reproduction strategies and high environmental tolerance), both in Europe and in America, with a tremendously negative impact, not only upon native fauna, but also on the river ecosystems they colonise, and are of serious consequence for different economic sectors (construction, water inlets of hydroelectricity, thermal and nuclear plants, etc.). These invasive bivalves cause rapid changes in the benthic community. They displace the native mollusc species, causing an increase in organic substrate cover *(macrofouling)* and favour the presence of oligochaetes and leeches (Darrigran 2002) *Corbicula fluminea* has already invaded the rivers of the Atlantic side of the Peninsula (Araujo *et al*. 1993 and Jiménez *et al*. pers. comm.) and has recently been found in the Ebro (López and Altaba 1997). In this river, too, the first invasion of *Dreissena polymorpha* has recently been recorded in Spain. The consequences of this invasion will be even more serious as this is a bivalve with byssus, which produces large agglomerations of individuals, with planktonic larvae, which facilitates dispersal and makes it extremely aggressive. The transfer of water from the Ebro to the rivers of the Levant will undoubtedly cause invasion. According to the results of Daufresne, *et al* (2004 and pers. comm.), these three species will be favoured by the increased water temperature in the rivers resulting from global warming. Indeed, among molluscs, which is the group that will benefit the most, the two species that most increased their densities in the 1979-1999 period were *Potamopyrgus* and *Corbicula.*

6.3.2.6. Interaction between climate change, vegetation, herbivores, human management and biodiversity in continental ecosystems.

The maintenance of biodiversity necessarily involves the maintenance of habitats. Changes in habitats deriving from human activity are recognised as being the main cause of species extinction. Climate change can directly affect habitats by affecting vegetation, but it is important to point out how activity by herbivores, exacerbated by human management, can accelerate certain processes.

- *Dehesas* and Mediterranean forests. The main use of these areas has been for extensive livestock farming, for which there has been a tendency to eliminate the shrub cover. *Dehesas* without shrubland are unsustainable in the long term due to the lack of natural regeneration of the trees. The main causes of the death rate of the seedlings are summertime drought and the impact of herbivores (Pulido 1999). The temperature increase and/or reduced rainfall lead to early withering of the herbaceous vegetation, which is associated with a greater impact by herbivores on woody plants (Rodríguez-Berrocal 1993). If forest and shrubland areas do not increase in comparison to *dehesas*, climate change could provoke less regeneration of the trees and greater impact by herbivores on the areas occupied by woody vegetation. If there is no intervention, the process could reinforce itself, leading to desertification. The change in use from domestic livestock farming to wild ungulates for hunting may favour management involving an increase in the areas with woody plants, with positive effects for biodiversity (Carranza 1999 2001).

Changes in traditional uses in wetlands, caused by a progressive loss of surface water, have led and lead to a decrease in the phreatic level of the waters by which they are fed, with their consequent salinisation. To this alteration we must add the desiccation and pollution of many of Spain's marshlands. Enrichment in nutrients and organic matter from nearby croplands, extensive farming, and industrial dumping lead to an increase in the degree of eutrophy of the wetland, a reduction of diversity, and the homogenisation of the flora and fauna. In addition to these threats, we must also consider others that have appeared in recent times, such as the use of coastal wetlands to harvest species of economic interest, or the introduction of exotic species like the American crayfish *Procambarus clarki*. This extremely voracious and aggressive species has thrived to the extent that it is now a real pest and a serious threat to many macrophytes. Furthermore, together with the aphanomycosis carried by the introduced individuals, it has destroyed and/or displaced the only autochthonous species of river crab, *Austrapotamobius pallipes,* which has been banished to pools or close to the source of the rivers. Even though it appears that *A. pallipes* populations are recovering, an increase in water temperature could favour the invasive species, allowing it to expand its distribution range upstream. This would put the native species at a clear competitive disadvantage. This species is protected by the Berne Convention (Annex II), Habitats directive (Annex V), UICN (vulnerable). The river crab has not been included in the National Catalogue of Threatened Species, although it is protected in several catalogues of certain regional autonomies.

6.3.2.7. Conclusions based on detected changes

Both hypotheses of future scenarios are confirmed in some cases, whereas they are unrealistic in others. The displacement of distributions would mainly affect species with a good capacity for dispersal (birds, certain insects), whereas it does not seem viable in others (amphibians, fish and most invertebrates). The new ecological challenges for the former in their new distribution areas could prevent colonisation. The alteration of ecological interactions might already be affecting many desynchronised populations with regard to their trophic resources, due to phenological changes, but this has only been confirmed in some cases. Neither the displacement of distribution areas (hypothesis I) nor the rapid adaptation to new ecological conditions (hypothesis II) appears to be viable solutions for most of the species studied.

With regard to future projections, no serious study has been done on this theme in Spain. It is not easy to base distribution models of animals on climatic data only, given the complexity of their ecological interactions with vegetation and with other animal species and of their patterns of habitat use for protection and reproduction. Studies done to date outside Spain present a worrisome panorama with regard to possible impacts. With the current knowledge of Spanish populations, we can state that if certain patterns detected up to the present continue, much of our animal diversity will disappear during this century.

6.4. MOST VULNERABLE AREAS

Among the areas most vulnerable to climate change, we could include coastal areas, wetlands, permanent water courses, which would become seasonal and seasonal ones that would have a more irregular flow or might even disappear, high mountain areas and humid pastures. The vulnerability is maximum for specific habitats (especially mountain ones) that are totally isolated and contain endemic fauna that have no capacity to migrate or where there is no possibility of creating natural corridors or where there is nowhere to migrate to. With climate change, large populations could disappear in the short term, and all of their available habitats in the medium term. There are several examples of this on the Peninsula, particularly in mountain areas in the South and Centre. With regard to vulnerable reptiles and amphibians, we must mention *Algyroides marchii, Lacerta monticola cyreni*, *Podarcis carbonelli*, *Lacerta schreiberi* and *Salamandra salamandra longirostris* (subspecies endemic to the mountains in southern Andalucia). Among the invertebrates, hydrobiid molluscs, which live in springs and small streams are a clear example of the disappearance, now a reality, of some populations and even species, previous to their being described (pers. obs.).

6.5. MAIN ADAPTATIONAL OPTIONS

There are several types of adaptational measures that can be taken in the event of climate change, in order to dilute or mitigate its effects on the biodiversity of terrestrial vertebrates and continental invertebrates.

6.5.1. Design of reserves and nature parks and habitat connection:

The design of reserves and nature parks should incorporate the possibility of migration and changes in distribution by means of interconnecting biological corridors.

6.5.2. Latitudinal and altitudinal gradients in the network of protected areas:

The network of protected areas should incorporate latitudinal and altitudinal gradients in order to allow for the protection of populations with geographic distributions in the process of geographic displacement due to climatic change. We should consider the areas of greatest altitude in the distribution limits of the species to be conserved (endemics, rare species, threatened and endangered ones).

Biodiversity conservation should pay attention not only to the protected areas, but also very especially to the generalised promotion of land uses that are compatible with conservation and capable of counteracting the effects of climate change.

6.5.3. Genetic diversity and conservation

Another consideration is that the genetic diversity of affected populations should be given top priority, because only this can ensure adaptation to climate change. It is important to support research in this field. Crossbreeding with foreign species favoured by climatic change may eliminate endemic genetic varieties in our country.

6.5.4. Genetic diversity and use of species for sports and similar uses

Other possible measures of adaptation to climate change applied without conservation in mind may exacerbate even more the situation of vertebrates and arthropods. Loss of certain species necessary for the control of other populations or for sport uses may lead to the introduction of foreign species, which could have pernicious collateral effects derived from competition with, or depredation on threatened species of vertebrates. The introduction of biological control agents for plagues of arthropods should be well controlled. The prevention of new or more virulent plagues resulting from climate change may determine the use of more pesticides with the consequent impact on the accompanying fauna and an increase of toxic compounds in the environment.

Fragmentation and certain types of management of deer populations provoke a decrease in allelic diversity and increases the degree of homozygosis (Martínez *et al*. 2002). For these cases, recommendations are available for mitigating effects (Carranza and Martínez 2002).

6.5.5. Hydric demands, persistence of species and conflicts over the resource

The increase in demand for water for human uses due to temperature increases and in a possible context of prolonged droughts, will possibly determine an increase in technological solutions that do not take into account the impacts on the biodiversity of species of vertebrates and invertebrates depending on permanent water courses (dams, canals, aqueducts, etc). Communication between water-courses and diverse faunas by canals, has dramatically affected populations of autochthonous species of river fish (Torralba and Oliva 1997, Elvira 2001, Elvira and Almódovar 2001,) and has definitely affected populations of aquatic invertebrates. The alteration of the structure of river courses (construction of dams and reservoirs) causes an alteration of thermal and hydrographic regimes which itself causes changes in entire communities (Power *et al* 1996). These effects can be exacerbated or counteracted (for instance, when a warm and temperate aquatic community changes to a cold water one as a consequence of the construction of a dam upriver) by tendencies to global warming.

Overexploitation of aquifers as a result of water scarcity will cause the permanent desiccation of springs with the consequent loss of species and communities inhabiting therein. Wetlands, in particular the inland marsh ecosystems of the Mediterranean region, mainly occupying sedimentary basins, may suffer a serious impact. The supply could be considered of a wetland with water from different basins, or with different physicochemical characteristics, in order to maintain levels more or less stable for use by the bird community, or for use as a water resource. These interventions could cause alterations to the ecosystem, in many cases irreversible ones. Artificial water supply can cause changes in the environment that impede the normal development of the biota characteristic of the wetland affected and even introduce species that displace the autochthonous ones, with the consequent changes in the original biocenosis. A clear example of this is the Las Tablas de Daimiel National Park, which, following desiccation, receives water from another basin (see Chapter XX). Following this episode, several sampling sessions have shown that the mollusc species described therein have disappeared (Araujo and Ramos, personal communication), and only empty shells can be found. The same thing might have occurred with other animal groups whose disappearance has left no visible signs.

The clear decrease in the flow of Mediterranean coastline rivers in the last century, fundamentally due to increased demand for water, may be responsible for the scarcity or lack of the Otter *Lutra lutra* in these rivers (Jiménez and Delibes 1990, Jiménez and Lacomba 1991).

6.5.6. Advantages and disadvantages of measures for the mitigation of climate change in relation to reforestation

One of the main mitigation measures contemplated in the context of climate change and in relation to the Kyoto Protocol is the creation of new forest masses that could serve as carbon sinks. This could have positive effects on the fauna depending on forest ecosystems. However, it could also cause serious problems for the conservation of terrestrial biodiversitiy. One of the main ones involves reforestation with fast-growing foreign species or the establishment of plantations with few species. The importance should be highlighted of conserving the existing masses of mature, slow-growing forests, compared with the alternative of reforestation with fast-growing species (if the priority objective really is carbon sequestration). Reforestation with fast-growing species will sequestrate carbon faster, but this will also be released faster (Körner 2001). It really seems quite frivolous to argue about which species is the most efficient for capturing CO_2 from the atmosphere when, on the other hand, CO_2 is being released by the massive deforestation of mature forests that constitute an important carbon store. Replacement of mature forests by plantations would be of no advantage to our autochthonous fauna, but would rather serve as an excuse to destroy whole masses of autochthonous forests and to eliminate habitats of conservationist interest, like agricultural steppes, mountain pastures or Mediterranean shrublands. Furthermore, substitution of mature forests with foreign species could lead to the impoverishment of the soils, and of the associated biodiversity, due to acidification and loss of plant organic matter that is vital for the balance of the ecosystem. Grants for reforestation are having pernicious effects in tropical countries, where native forests are being destroyed to justify the reforestation of barren land, funding agencies not being informed that this land was previously covered with forest. The simplification of habitats caused by plantations or single cropping with one or few species can only be bad for biodiverity. The plantation of species that demand water in order to grow rapidly can only worsen the drop in phreatic levels and the destruction of habitats of vertebrates or invertebrates depending on aquatic habitats. In a scenario of climate change, it is important to conserve the Mediterranean maquis given its low capacity for evapotranspiration compared to other forest habitats that lose more water than they retain (see terrestrial ecosystems).

In Mediterranean ecosystems it is necessary to promote the natural regeneration of forests (especially *Quercus* spp), by allowing for the ecological succession of the Mediterranean shrubland in large areas inserted into the *dehesa* areas (Pulido 1999, Carranza 2001). However, in relation to reforestation policies, we must point out that the Mediterranean environment has been shaped and transformed by incessant human activity for thousands of years, which has led to a landscape mosaic comprising fields of crops, pastures bordering with herbaceous vegetation or shrubland, cohabiting with original plant formations which have been managed by man for thousands of years (Díaz-Pineda *et al*. 1998). This historic process of transformation of the environment has surely conditioned, to a great extent, the composition of the fauna and vegetation currently found in the Mediterranean basin (Blondel and Vigne 1984, Erhardt and Thomas 1991, Galante 1994, Mönkkönen and Welsh 1994, Samways 1994). Thus, the highest levels of entomological diversity and the highest percentages of endemisms are found in open spaces (Galante 2002, Verdú and Galante 2002, Martín *et al*. 2000). Thus, a generalised reforestation policy, along with the promotion of changes in land use, encouraging the abandonment of traditional agricultural and livestock farming activities, may become a very negative factor for the conservation of Iberobalearic biodiversity, which will lead to the rapid disappearance of numerous species of insects and other invertebrates.

6.5.7. Interactions between the use of different types of renewable energy and fauna

Other possible mitigation measures considered involve opting for hydraulic or aeolic energy. The former would be based on new dams and the fragmentation of our rivers, the latter on the construction of windcraft parks, with annexed infrastructures which could contribute both to the possible death of birds during migration and to serious alterations or damage in the surrounding environment resulting from construction. The main migration routes of birds from Europe to Africa cross Spanish territory (Bernis 1966)

The few data available in this respect for rivers (Daufresne *et al*. 2003) suggest that artificial warming foci, such as thermal and even nuclear power plants, can on occasions affect the surrounding communities, although they do not appear to have a significant effect on the tendency towards upstream displacement in the present zonal distribution of fish and invertebrates in rivers.

6.6. IMPACTS ON OTHER SECTORS OR AREAS

Agricultural and cattle-raising activities can be seriously affected by climate change. Measures taken against prolonged droughts (dams, containments, over-exploitation of aquifers) will have adverse effects on animal biodiversity (see other sections). A greater incidence of pests could imply an increase in pesticide emission into the medium. This, in turn, could favour the selection of pests that are increasingly more virulent. Increased incidences of parasitosis in domestic animals will require an increase in antiparasitic treatments, which could favour selection for greater resistance in parasites and increase their virulence.

Sport hunting and fishing currently constitute economic activities involving many people and which generate large amounts of capital, as well as affecting increasingly larger areas fundamentally managed for the practice of these activities. The target species of hunting and fishing will be affected in the same way as other species by the aforementioned potential changes. The introduction of varieties or breeds which are poorly adapted to the Mediterranean climate could cause further problems.

Supplementary food is given to the game to mitigate the effects of summer drought in the southern half of Spain. The effects of this supplementary feeding system are usually undesirable (Carranza *et al* 1995, Sanchez-Prieto *et al*., in press) and could be exacerbated with climate change. An increase in the areas of forest and shrublands, along with the suitable insertion of these in mosaics, might contribute to attenuating the need for supplementary food in summer (Carranza 1999; 2001).

Management practices that are incompatible with the conservation of game species and freshwater fish and their habitats ought to be controlled (Carranza and Martínez 2002), but the use of the territory for hunting may be more compatible with conservation of certain species than traditional uses like extensive agriculture and livestock farming (Carranza 2001), and it can also be more easily used to prevent the effects of climate change than agriculture and livestock farming.

6.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

None of the studies reviewed here can irrefutably demonstrate that climate change alone is responsible for the tendencies detected in species and communities (Hughes 2000, McCarty 2001). The destruction, degradation, fragmentation and contamination of habitats caused by changes in the models of economic development are occurring simultaneously with climate change, and to separate the signs of these synergic processes would require much more detailed and costly studies than those that the Spanish scientific community has been able to implement to date. This does not mean that we cannot propose possible effects of climate change, provided that the estimates upon which the climate model is based, as well as the predictions of effects on populations are clearly established.

With regard to invertebrates, there are also numerous factors that should be studied in order to evaluate the possible effects of climate change on their populations. One of the key questions to be researched is the relationship between the changes in the distribution area of the species and climate change, and in this process the influence of the present changes in land use and in hydric resources and habitat fragmentation should be analysed. To this we must add the changes in phenology that climate change is causing and which should be analysed together with changes in distribution. Changes in inter-species ecological interactions and the interaction between these species and the environment should be subjected to more in-depth study.

6.8. DETECTION OF CHANGE

Change can be detected by means of any long-term study of animal populations capable of eliminating sources of variation resulting from other human impacts on habitats (changes in policy, infrastructures, housing development, pollution, introduction of exotic species, etc,.). This is obviously easier in populations in areas little affected by humans, like protected areas. But there are also groups of species, which have proven to be extremely vulnerable to environmental change, and population collapses have been detected in remote or protected regions. Among the vertebrates, we can highlight amphibians in this sense, due to their morphology and physiology. There is also a global observation network for the observation of changes in amphibian populations, which facilitates the transfer of information at international level. Migratory birds, due to the discrete nature of the phases of their annual cycle, offer good possibilities for the detection of changes in phenology and in behaviour. The animals living in high-mountain areas can also be good indicators of changes, as these areas are real ecological islands the area of which would gradually be reduced by climate change.

6.9. IMPLICATIONS FOR POLICIES

6.9.1. Scientific policy

The Science and Education Ministry should promote research into the effects of climate change on the processes affecting the biodiversity of terrestrial organisms. Most of the projects approved up to now only contemplate changes in the past. Hardly any prospective projects or ones related to detection of the effects of climate change have been approved to date. These projects ought to appraise the effects of climate change and its relationship with profound changes in land uses and with habitat fragmentation. International scientific cooperation, especially within the EU, is the only way to advance research on such complex subjects that are not limited to the strict geographic boundaries of our country. This cooperation should be encouraged through programs like “Global Change”, within the program framework of the EU.

6.9.2. Environmental policy

The Environment Ministry (DGB, OA national Parks) and the Regional Governments should take a stance on the conservation of the network of protected areas. This policy should be applied at the level of regional autonomies, given the geographic scale of the problems.

Areas containing species particularly affected by climate change could be subjected to special protection in order to reduce to a minimum the effects of climate change (protection of hydrological and forest resources, control of all types of land uses, like excessive livestock farming, tourism or housing development). It would be interesting to appraise the classification or creation of “zones or areas particularly sensitive to climate change” for areas with unique original ecosystems or with endangered or endemic species that have no alternatives for the displacement of their habitats and that can become extinct. Examples of these areas are high-mountain territories, water courses containing vulnerable species and wetlands and other aquatic ecosystems such as springs and small strems, which are not subjected to any legal protection.

6.9.3. Regional and local tourism policy

To be implemented by the Regional Autonomies (Tourism Depts.) and by the City Councils (Municipal Tourism Depts.) located in the surroundings of protected natural areas. Alteration by tourism of vulnerable high-mountain areas or of lacustrian-river areas should be strictly limited.

6.9.4. Hunting and freshwater fishing policy

The Regional Autonomy would be involved (Agriculture and Fisheries or Environmental Depts.). The introduction of foreign species of fish for sports fishing should be controlled or prevented if the intention is to conserve the rich diversity of endemisms of freshwater fish that still exist in our country. The introduction of varieties or species for hunting typical of other regions should also be controlled in order to avoid negative effects through crossbreeding on the autochthonous varieties which are better adapted to the Mediterranean climate.

Sport fishing activities, and even the use of boats on lakes and lagoons to this end, can cause the accidental translocation of invasive species as e.g. of the larvae of *Dreissena polymorpha*. Upstream movement of sport fishing boats on the river Miño has spread upstream the species *Corbicula fluminea*. Appropriate measures need to be established to control carriers of invasive species (renovation of fishing tackle, cleaning boats on changing basins, etc.), and there is also a drastic need for follow-up in this respect. Awareness of the population is essential in order for these measures to be effective.

6.10. MAIN RESEARCH NEEDS

6.10.1. Creation and maintenance of long temporal series

As can be deduced from the incorporated information, there are very few long temporal series in Spain that can be used to explore the possibilities of changes in the phenology or dynamics of populations. Long-term studies should be established and funded dealing with animal populations located in habitat that do not suffer (or hardly) from human effects different from climate change. Short temporal series prevent us from separating the effects of possible climate changes from natural demographic variations. Long temporal series permit us to explore the effects of extreme climatic events (such as that of the summer of 2003), and variation of climatic conditions in relation to mean temperature increases.

At present, there exists a phenological database of plants and animals (birds and insects) initiated in 1940 by the Agricultural Meteorology Service, belonging to the National Meteorology Institute (NMI). From the start, different phenological phases were recorded (for example, flowering and leaf unfolding in plants, or the arrival and departure of migrating birds) in between 100 and 200 stations throughout the Peninsula, the Balearic Isles and the Canary Isles. The data were collected by observers who, under specific instructions, forwarded the information on a monthly basis. These data are being computerised by J.J. Sanz within the framework of a collaboration agreement between the NMI and the MNCN - CSIC- (National Museum of Natural Sciences - Higher Council for Scientific Research). The number of observations has been gradually decreasing since 1940, and if this database is not revitalised, its future is quite uncertain. For example, in the 1950s, there were around 300 observations of arrivals of swallows to different locations; this number has dropped to 150 in the 1980s and in the last 5 years it has dropped below 100 locations per year. The main problem with this phenological database is the low entry of data from new observers. This type of phenological database should be promoted with the use of Internet as a means of communication between observers. It would be a good idea to use park rangers as phenological observers, given their suitable biological training for this activity. Internet could be used to reduce costs as much as possible, and the observers would be encouraged to contrast their data with the existing ones. The database should have someone in charge of validating the observations in order to provide the information to the Administration. The objective of this information would be to provide bioindicators of possible climate changes in the present or nearby future. Furthermore, this activity could be promoted among conservationist NGOs specialised in certain organisms, like SEO/BirdLife for birds. This NGO has a great potential with regard to observers, who are well distributed throughout the Peninsula and the islands, and who could provide valuable data. Indeed, there are already programmes underway (SACRE), the future results of which can be used as bioindicators of global change.

6.10.2. The Establishment of research programs on latitudinal and altitudinal gradients and distribution limits

Given its geographic location and complex orography compared to other European countries, Spain offers many unique possibilities for research along latitudinal and altitudinal gradients. Research on animal population dynamics and adaptations along these gradients would provide important information to assess animal species adaptation to rapid climate changes. The life histories of some populations could exhibit altitudinal microevolutionary diversification as a result of having adapted to altitudinal gradients. This altitudinal diversification could be more important than latitudinal diversification and deserves to be studied and preserved. Altitudinal biodiversity could be seriously affected by climatic changes. At the same time, our country's geographic position offers a unique opportunity to study the ecological factors that determine distribution limits of animal species, and how these limits may change. This type of research must be supported if we wish to have some predictive ability over the future of our animal populations.

6.10.3. Basic studies of the ecology or ecophysiology of wild species in order to allow for minimally reliable predictions of bioenergetic models

There is also the need for further study of the ecology or ecophysiology of wild species in order to predict bioenergetic models that are reliable. It is very important to evaluate the interaction between climate change and other environmental stress factors, by magnifying the effects on wild species of single factors in isolation.

6.10.4. Surveillance systems for possible population collapses

There is an important need for surveillance systems inside and outside reserves in order to detect population collapses and local climate changes. Thus, the near-extinction of the Iberian lynx almost caught the Administration and the conservation NGOs by surprise. Many species, endemic but less charismatic than the lynx, like the Pyrenean desman, are disappearing from large areas of our country, without any apparent reaction by the professionals or people responsible for managing the fauna.

6.10.5. Evaluation of the efficiency of the possible mitigation measures

There is also a need for evaluations of the impact of the possible measures proposed for adaptation and mitigation.

6.10.6. Taxonomic studies in invertebrates

Predictive models of possible changes in the functioning of ecosystems resulting from climate change (species substitution, interaction among the elements of communities, etc.), are seriously hindered by the lack of taxonomic knowledge of the species that integrate them, and of what role they play in the ecosystem.

A priority is therefore: 1) to increase taxonomic studies, in particular of the less known animal groups, and of those that serve as bioindicators, and 2) to develop tools to bring within the reach of ecology scientists, environment managers and society as a whole, easier access to available information.

6.10.7. Conservation Biology for the future

Research into conservation biology and the development of long-term projects ought to be a priority of the Administration in order for future reports to provide more data and less speculation than at present. The study of animal population dynamics should be central to conservation biology studies related to climate change. The length of the reproductive season can affect interactions with predators and parasites, as well as population size and density.

There is a need to promote the study of life cycles, reproduction strategies and population dynamics in relation to altitude and latitude, etc., and of species that are a key to the functioning of ecosystems as well as on invasive species in order to be able to apply the best practises for the protection of native fauna and the control of alien species.

With regard to arthropods in general, research programmes should be developed dealing with the effects of climate change on:

- Groups of endemic insects associated with Iberian transversal mountain ranges, the distribution of which is previous to the Pleistocene glaciations, like the case of *Parnassius apollo*. We could say that they are trapped within their limits, with no possibility to emigrate northwards, and the only response their populations can therefore have involves a vertical displacement towards higher elevations.

- Groups of endemic arthropods, in many cases non-flying wingless ones, or those with little chance of displacement, associated with arid ecosystems with extreme conditions of humidity and temperature, due to the fact that global warming may make the survival of their populations unfeasible.

- Groups of predatory insects and parasitoids, in relation to their biology and that of their prey and their hosts. The lack of synchronisation in their cycles may have serious consequences with regard to increased plagues in crops.

- Groups of migrating insects, in relation to the advance periods of their displacement phases. There could be different consequences: their arrival to ecosystems may not be synchronised with the phenology of food plants, they may not be able to implement their pollinating processes, which are so important for the maintenance of Mediterranean endemic plants

(Pérez Bañón *et al*. 2003), the early appearance of plagues (EXAMINE, project V, Seco pers. com.), etc.

- Insect dispersal related to potential changes in distribution of food plants.

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7. IMPACTS ON HYDRIC RESOURCES

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ABSTRACT

Climate change involving temperature rises and, in Spain, reduced rainfall, will cause a decrease in water yields and increased demand for irrigation systems.

The impacts of climate change on water resources will not only depend on the yields of each hydrological cycle, conditioned by land use and cover, temperature and the temporal structure of rainfall; the water resources system and the way this is managed are also a determinant factor of water sufficiency or scarcity in relation to global human needs.

Water resources are very sensitive to temperature increase and reduced rainfall, precisely in areas with high mean temperatures and low rainfall. The most critical areas are semiarid ones, where reduced yields can reach 50% of the area's potential resources.

Temporality in the distribution of rainfall and temperatures often has a greater influence on the generation of water resources than the mean values of these two climatic parameters.

For the 2030 horizon, considering two scenarios, one with a 1ºC increase in annual mean temperature and another with a 5% reduction of annual mean rainfall and a 1ºC temperature increase, decreases can be expected in mean water yields in natural regime in Spain, of between 5 and 14%. The Guadiana, Canary Isles, Segura, Júcar, Guadalquivir, Sur and Balearic Isles catchments are where the impact on water resources will be most severe.

For the 2060 horizon, with a scenario of a 2,5 ºC temperature rise and an 8% decrease in rainfall, global reduction of water resources is predicted of 17% on average for the Peninsula, along with an increase in the interannual variability thereof. These changes will be greater in southern Spain.

In an extreme scenario (unlikely) involving a 15% decrease in annual mean rainfall and a 4ºC temperature rise, total yield will range from 5% on the coast of Galicia 22% in Guadiana II 20% in the Júcar catchment, and 20% in the internal catchments of Catalonia.

The main mitigation options are aimed at optimising water use (demand management), improving the water resources system and the management thereof, in particular groundwater, and increasing unconventional resources, catchment of rain or dew water, transfers between catchments, desalinisation and reuse.

Variation in water resources resulting from climate change is conditioned by the influence of other sectors also affected by the changes. Changes in water resources, in turn, have a great effect on many other sectors, particularly on aquatic and continental ecosystems, on animal and plant biodiversity, the agriculture, forestry, energy and tourism sectors, on human health and on natural risks of climatic origin.

In estimating water resources in relation to climate change, there are uncertainties inherent both to databases and to the process of resource generation, the former being of greater relative importance. Among these uncertainties we can highlight foreseeable scenarios, spatial and temporal distribution of rainfall, the behaviour of land use and cover, aquifer recharge and the limitations of simulation models.

The change in water resources can be seen in the measures established in Spain involving control systems, which in some cases are well implemented or are being improved, and in others should be implemented in a more generalised way. Among the latter, we should

recommend the design and implementation of water use control networks, in relation both to surface and groundwater, and metering networks in springs and sources.

The decrease in water resources affects many sectors, the regulation of which is based on the definition of specific policies. The change would involve the necessary re-modelling and redefinition of new policies, related to science and technology, water, energy, agriculture, environment and land planning.

Climate change calls for the research needed to improve predictions of rainfall and temperatures, as well as the spatial and temporal distribution thereof, and research aimed at defining methods for generating climate data series based on scenarios, and at providing better and more reliable methods of evaluation of evaporation and evapotranspiration, the operation of groundwater in the soil, the interception and reserve of water that can be used by plants, and research aimed at establishing more reliable aquifer recharge processes and developing models for computerising yield calculation and catchment management models.

7.1. INTRODUCTION

7.1.1. General consideration of the impacts of CC on hydric resources

The origin of the hydric resources available to humanity is found in an imbalance between continents, between the rainwater that falls and that which evaporates or evapotranspires, the former clearly constituting a surplus. In the oceans, the phenomenon is the opposite; they are deficient and evaporation is approximately 10% greater than rainfall. The surplus of the continents flows to the sea by the rivers, compensating the deficit in the oceans (Figure 7.1).

The potential hydric resources available to humankind to satisfy all of our needs depends precisely on these surpluses on the continents, between rainwater and that which returns to the atmosphere.

The water that exists is nature is constant, as a result of the principle of conservation of mass, which constitutes a cycle that continuously changes from a liquid or solid state to vapour, and vice versa. Climate governs this cycle, and climatic changes will therefore necessarily give rise to changes in the time and space of available water resources.

Changes in rainfall directly condition the water falling upon the continents and changes in temperature modify evaporation and evapotranspiration values, and alter the amount and characteristics of runoff waters.

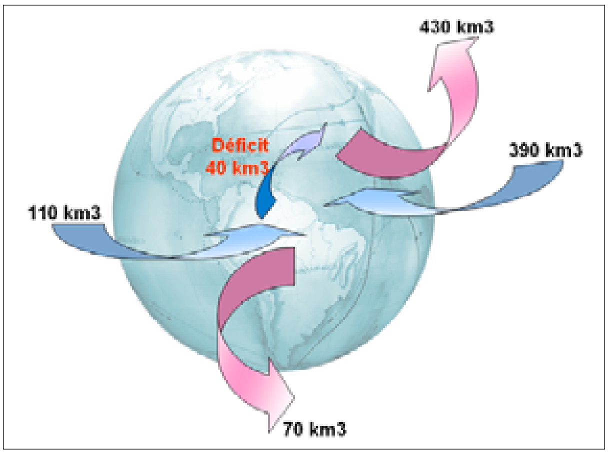


Fig. 7.1. *Global water balance (thousands of km^3)*

Given that runoff only occurs when the soil presents surpluses, or when rainfall intensity is greater than infiltration capacity, it is clear that temporal distribution and rainfall regime will affect the generation of runoff as much, or more, than the volume of rainfall itself.

Climate Change consequently has a direct and vitally important effect Hydric Resources. The impacts on these resources will be seen not only in variations in amounts, but also in a change in quality and in temporal distribution.

A lower volume of available water would worsen the quality thereof (National Climate Programme, MOPTMA – public works, transport and environment ministry – 1995) and phenomena such as the rise in sea level associated with global warming, and the fall in piezometric levels in aquifers hydraulically connected to the sea would favour pollution phenomena due to marine intrusion.

Water yields, considered to be the total volume of annually accountable water at one point of a catchment in natural regime, are initially conditioned by rainfall, temperature, land use and soil cover and the characteristics of the soil and subsoil.

Hydric resources, in the correct sense of the term, understood as volumes of water capable of satisfying water needs with regard to quantity and quality, time and space, are in turn conditioned by exploitation, temporal structure of demand, the available water resource systems (surface water and groundwater) and the operational rules defined for the system or the management rules thereof.

In short, it is the effort related to the regulation, supply, transport, distribution and quality protection by the Water Resources Systems, for both surface and subterranean waters, which constitutes the final stage, or group of factors, that condition the truly useable water resources.

Consequently, there are two groups of factors directly affecting the quantity and quality of available water resources, both endogenous and exogenous (Figure 7.2).

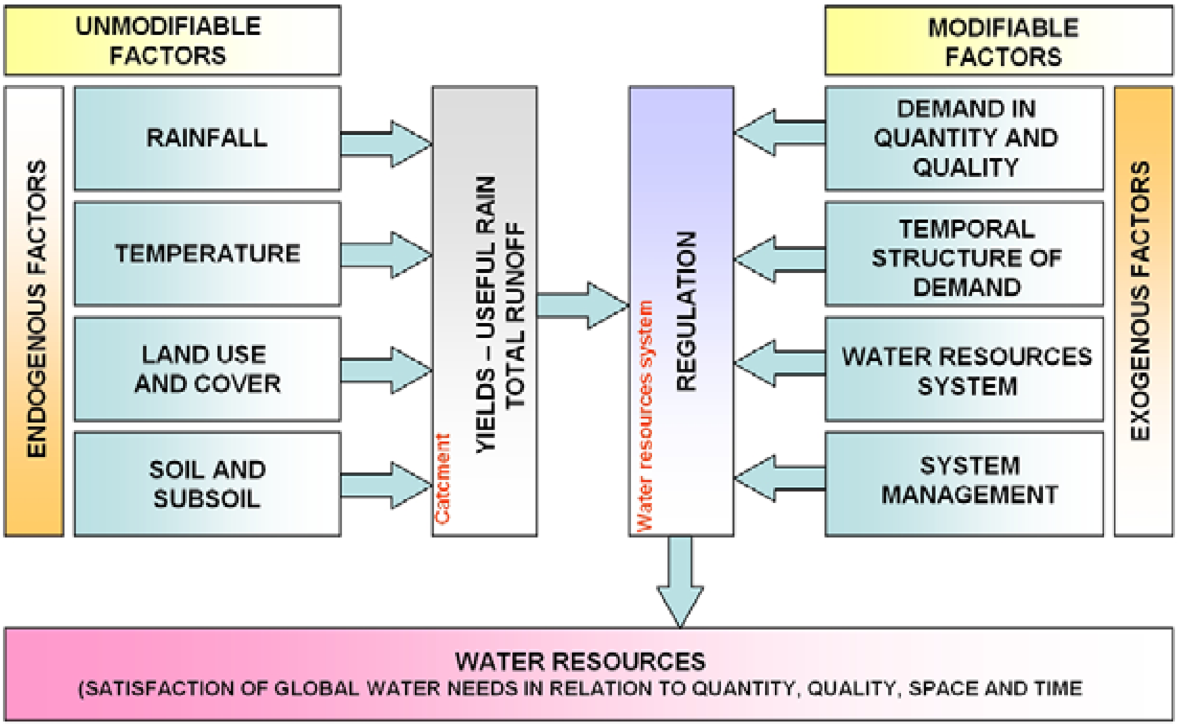


Fig. 7.2. *Table of factors intervening in the generation of water resources*
** Factors conditioned by land management, not usually integrated into water resources management.*

The first ones cannot be modified by human action and consequently, they are directly responsible for variation in yields in the hydric cycle. The only exception is land use and cover, factors which clearly condition the yields (Bosch and Hewlett 1982), but the management of which is usually independent from hydric resources management. These yields adjust to demand and the structure of this, making use of the water resource systems (surface and groundwater), which are suitably managed through management rules that are frequently designed with the support of management models.

Climate change with temperature increases, and in Spain, with reduced rainfall, will essentially cause a decrease in water yields and increased demand for irrigation systems. The real impact, however, will depend on the available water resources system and the way this is managed.

Demand and structure thereof, system and the management of this, are the exogenous and modifiable factors that can allow correction or adjustment in relation to the impact caused.

With regard to demand and its structure, there exist actions related to the optimisation of water use.

In relation to the system and the management thereof, there are options for modifying or expanding the system, or for improving management by means of operations backed by management tools (Figure 7.3).

Besides, there is always the option, frequently more costly, of increasing available resources by means of transfer between basin catchments, desalinisation of brackish waters or seawater and re-utilisation of resources with all the necessary precautions.

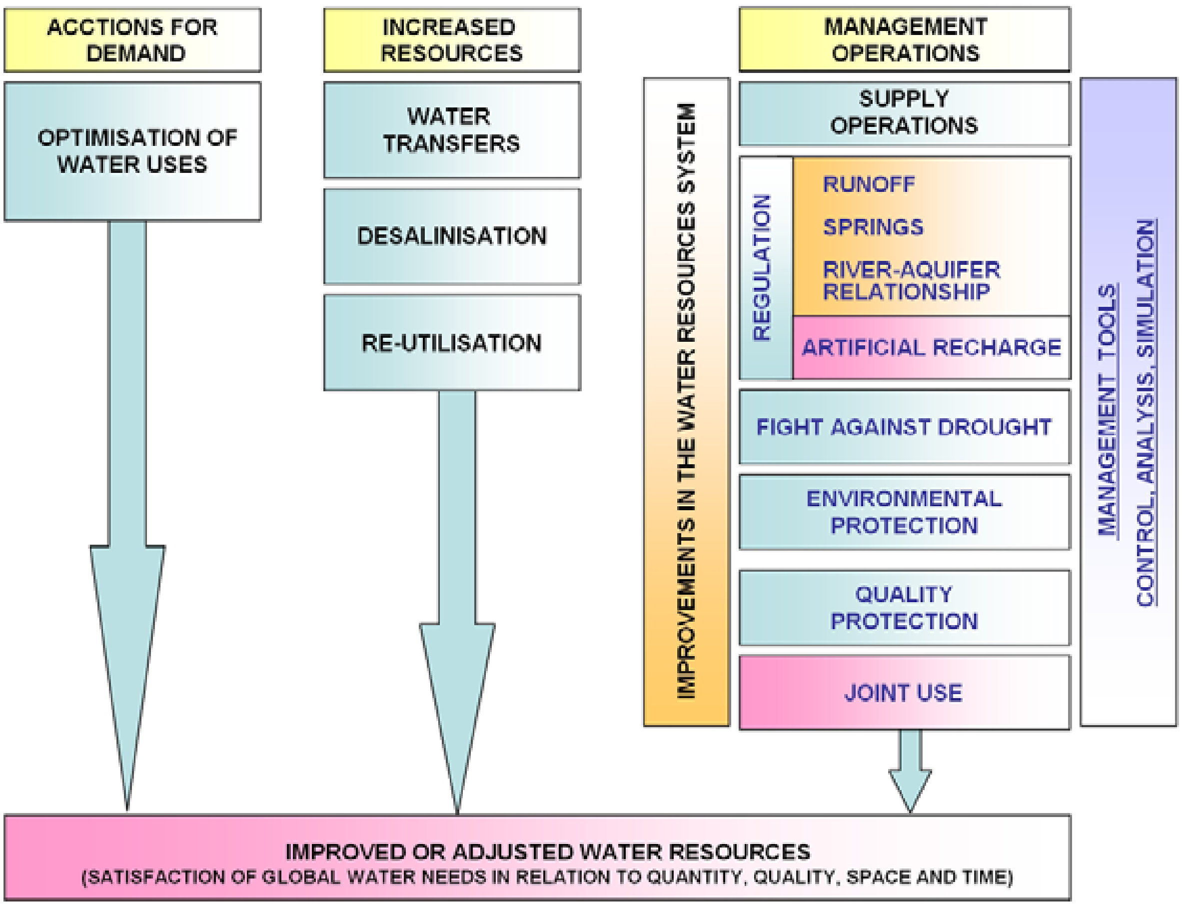


Fig. 7.3. *Table of possible corrective measures based on management*

One clear conclusion in relation to the impacts of climate change on water resources is that we are dealing with a system with a high degree of uncertainty. Resources do not only depend on the yields provided by the hydrological cycle, which are conditioned by the amount and temporal structure of rainfall, temperature and land use and cover, whereas demand depends not only on climate, but also on the technical and socioeconomic changes that will take place in the future. Finally, it is the system of available water resources and the way this is managed which fundamentally conditions the sufficiency or scarcity of water in relation to demand.

The conclusions of the ACACIA project in Europe (Parry 2000) with regard to water management are not exactly encouraging: In the water sector, the major policy implication of climate change is that it is no longer possible to assume that the future hydrological resource base will be similar to that of the present. This is important in the context of sustainable water management. Water managers, at all levels, therefore need to (a) develop methodological procedures for adopting a scenario-based approach to strategy or scheme assessment, and (b) develop adaptive techniques that allow incremental adjustments over time. A second major implication is that the amount of climate change might make it more difficult to move to more sustainable management of water resources, particularly in southern of Europe.

One clear conclusion with regard to the impacts of climate change on hydric resources is that these do not only depend on the yields from the hydrological cycle, which are conditioned by the soil, temperature and the temporal structure of rainfall, but also on the system of available water resources and the way this is managed. This constitutes the set of factors that basically conditions the sufficiency or scarcity of water in relation to global human needs.

7.1.2. Water resources in Spain. Surface water and groundwater

In Spain, yields by rivers to the sea have been well gauged throughout time, due to the high degree of development of the Water Resources System and to the importance of water availability in the national economy. The gauging network, however, was not designed to establish the hydrological response of natural systems, but rather, it is clearly oriented to the operational management of surface resources.

Taking into consideration the high level of water use in Spain, it is not easy to calculate the yields of rivers in natural regime, given that the flows measured therein will be altered by extractions for the different water uses and applications. Evaluations in natural regime are not based on gauging data, but rather make use of rainfall-runoff models.

The White Paper on Water (MIMAM 1998) contains data on evaluations made since 1967, Table 7.1, in which the scant differences between those made for each year can be appreciated, which makes them reliable and consistent.

These figures represent total runoffs, including surface waters and groundwater, and it must be understood that of these figures, one part would be strictly surface runoff and the other groundwater.

Several studies, however, indicate a significant decrease in yields from the main rivers during the second half of the XX century (figure 7.4), some of which cannot be justified by increased consumption (Prieto 1996; Flores-Montoya *et al*. 2003; García-Vera *et al*. 2003).

Table 7.1. *Estimation of total in natural regime.*

Sphere of planning	1967 (a)	1980 (b)	1993 (c)	1998 (d)	1998 (e)
Norte	37.500	38.700	42.088	42.258	44.157
Duero	13.200	15.900	15.168	15.168	13.660
Tajo	8.920	10.250	12.858	12.230	10.883
Guadiana	4.895	5.100	6.155	6.168	5.475
Guadalquivir	7.300	9.400	7.771	7.978	8.601
Sur	2.150	2.690	2.418	2.483	2.351
Segura	884	960	1.000	1.000	803
Júcar	2.950	5.100	4.142	4.142	3.432
Ebro	17.396	18.950	18.198	18.217	17.967
C.I. Catalonia	1.700	3.250	2.780	2.780	2.787
Total Península	**96.895**	**110.300**	**112.588**	**112.424**	**110.116**
Balearic Isles	-	690	745	562	661
Canary Isles	-	965	965	826	409
Total Spain	**-**	**111.955**	**114.298**	**113.812**	**111.186**

(a) PG (1967). Water resources. II Economic and Social Development Plan. Presidency of the Government.
(b) MOPU –public works ministry (1980). Water in Spain. CEH (hydrographic studies centre), DGOH (waterworks dept.) . Also in Heras (1977).
(c) MOPTMA-public works, transport and environment ministry- (1993b). Draft Report of the PHN (national hydrological plan) Law.
(d) *1998 Data on Catchment Management Plans.*
(e) 1998 Data on the evaluation contained in the White Paper on Water.
Note: The figure in the Ebro Catchment Plan (column d) does not include the resources of Garona or Gallocanta.

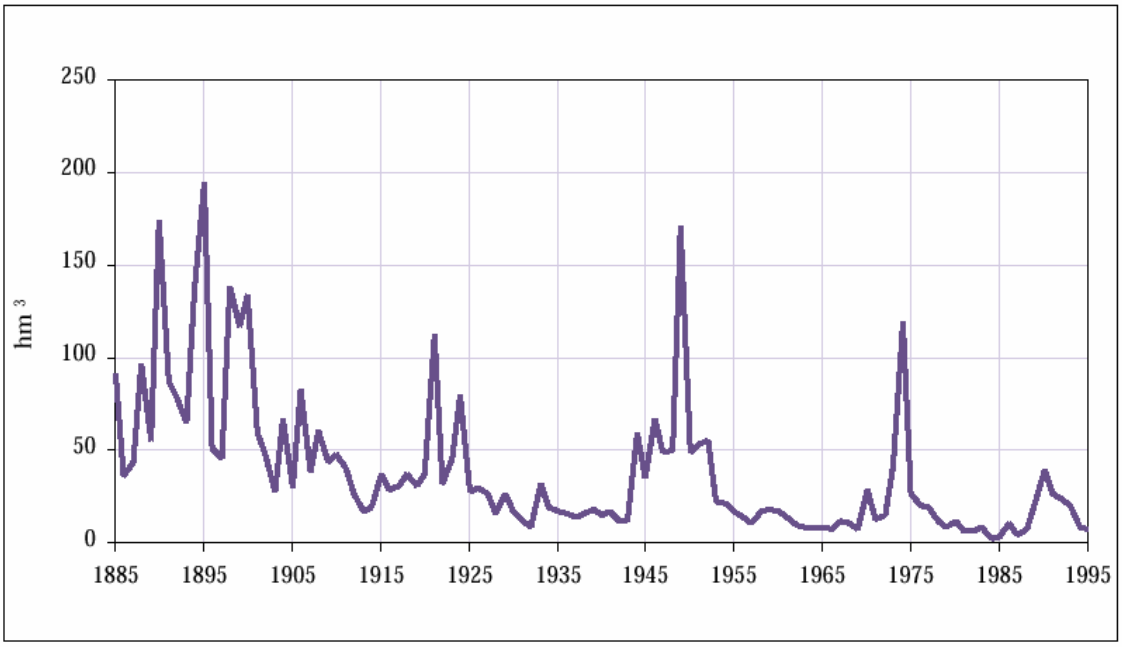


Fig. 7.4. *Series of annual yields of the river Guadalentín to the Puentes dam since (MMA Environment Ministry 1998)*

The values of groundwater flow have also been evaluated on multiple occasions with sufficient thoroughness, mainly in the regional studies of the National Groundwater Research Plan, IGME (geology and mining institute). Table 2 shows the values of the groundwater for the catchments of the large Spanish rivers, synthesised in the White Paper on Groundwater (MOPTMA (public works, transport and environment ministry)- MINER (industry and energy ministry) 1994)

Table 7.2. *Estimation of groundwater yields. Source: Catchment plans and White Paper on Groundwater (MOPTMA-MINER 1994).*

Sphere of Planning	Outcrop of permeable rocks. Area (km2)	Recharge by rain and flows (hm3/year)	Recharge by irrigation (hm3/year)
Norte	5.618	2.997	0
Duero	52.799	1.840	1
Tajo	17.475	1.565	0
Guadiana	14.754	787	20
Guadalquivir	15.140	2.573	16
Sur	5.305	865	69
Segura	6.958	674	83
Júcar	23.781	3.011	480
Ebro	17.057	4.433	586
C.I. Catalonia	6.616	938	45
Total Península	**165.503**	**19.683**	**1.300**
Balearic Isles	3.674	517	69
Canary Isles	7.384	681	0
Total Spain	**176.561**	**20.881**	**1.369**

In short, Spain's rivers in natural regime carry to the sea around 110,000 hm^3/year, of which around 90,000 hm^3 are strictly surface runoff and the other 20.000 hm^3 that have been transported through the aquifers are of subterranean origin, although the temporal stability of these yields has not been sufficiently studied.

7.1.3. Spatial and temporal heterogeneity of water resources in Spain

The heterogeneous spatial and temporal distribution of rainfall in Spain, much more evident than in other neighbouring countries, results in an extraordinary variability in yields over time and also in great variation in yields in the different catchments.

	TOTAL RUNOFF	TOTAL USES
NORTE CATCHMENT	39.000 hm³/year	930 hm³/year
SEGURA CATCHMENT	900 hm³/year	1.300 hm³/year

Fig. 7.5. *Comparisons between yields and water uses between catchments in "dry" and "humid" Spain.*

Figure 7.5 illustrates the needs and runoffs of two Spanish catchments; Norte and Segura, showing the difference between the two situations in order to deal with hydric demands. These differences are responsible for the existence of "dry" and "humid" Spain.

Taking as a reference the tables in the White paper of Water, MMA 1998, Figure 7.6 and Figure 7.7, the extraordinary differences can be seen between the runoffs of the different catchments and the variability in time of the yield.

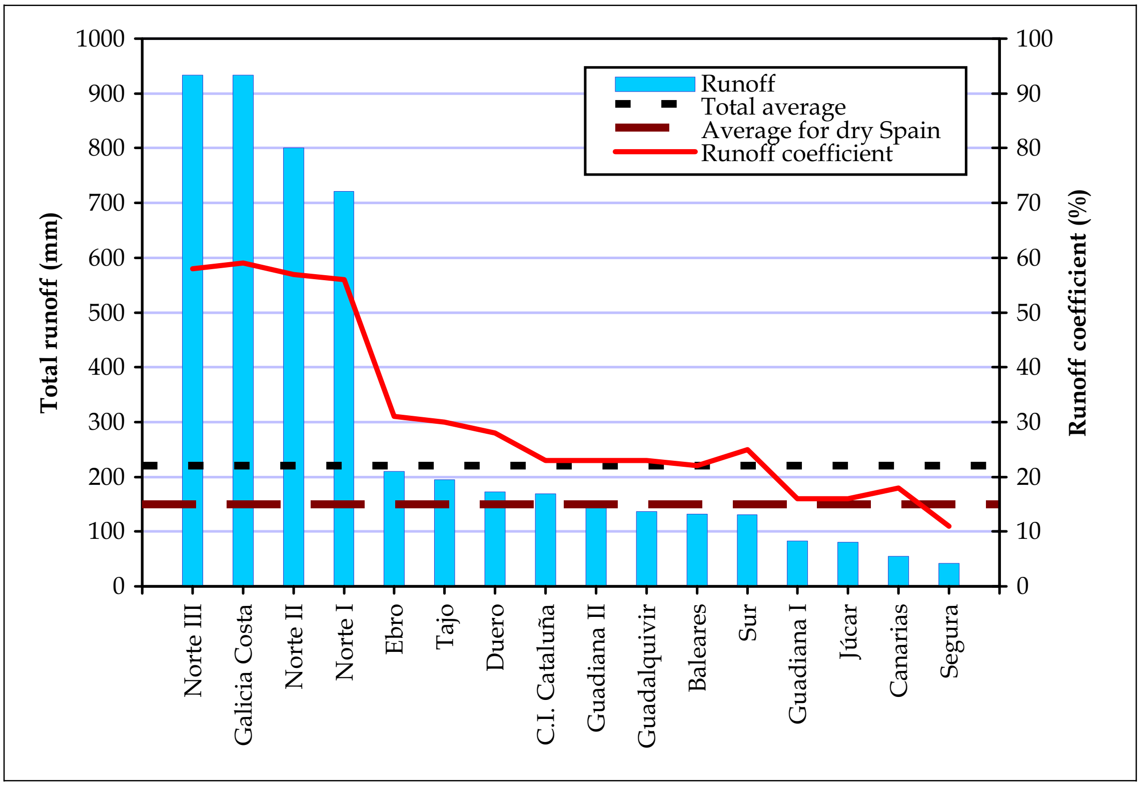


Fig. 7.6. *Annual total mean runoffs (mm) and runoff coefficients in natural regime in the different territorial spheres of the Catchment Management Plans. According to the White Paper on Water. MMA 1998*

The Norte catchments present excellent runoff values compared with the others, especially with those of Segura, Jucar, Canaries and Guadiana I. But it is precisely these catchments that present the highest consumption levels, mainly for irrigation.

Figure 7.7 shows runoff values in Spain, simulated in natural regime for the series 1940/41-1995/96, in which minimums of 50,000 hm^3/year and maximums of 220,000 hm^3/year can be seen, for an average of 110,000. This spatial heterogeneity, is another of the big problems of hydric resources in Spain; the amount that the hydrological cycle will provide is a factor of great uncertainty. These basic problems can only be approached by means of a large-scale and appropriately managed water resource system.

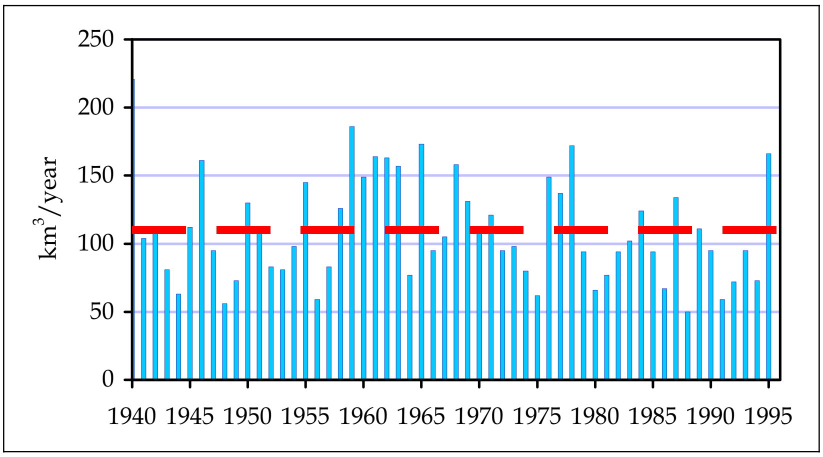


Fig. 7.7. *Series of total annual yields in natural regime on the Spanish Mainland (1940/41-1995/96 period)*

7.1.4. Water uses and applications in Spain

Spain has a long tradition of water uses. Mainly as a result of our well-developed agriculture and high potential for hydroelectricity, a large amount of reservoirs and groundwater captures have been built.

In many of the irrigation systems, vestiges of Roman construction can be found, and construction of these systems was probably started even earlier, but it was the hydrological systems of the Arabs that gave rise to the rich and fertile valleys of Granada, Valencia, Murcia and Aragón

The origin of the spectacular current development surely leads us to certain public figures of the last third of the XIX century, particularly Joaquín Costa and Macías Picavea, who promoted decisive action by the government aimed at regulating water yields and to extending irrigated areas, as a main objective of general economic policy.

Water use in Spain, however, has always been known to have problems, mainly due to the climate, partly semiarid, to the spatial and temporal heterogeneity of rainfall and certainly to the economic structure, with great involvement of agriculture, requiring large volumes of water precisely in summertime, when it is most lacking.

The table of Figure 7.8 synthesises some of the secular problems related to water use in Spain.

THE CLIMATE:	Development factor and aggression factor
RAINFALL:	Low and anarchic in time and space
ECONOMIC STRUCTURE:	Intense participation of agriculture and tourism
CROP REQUIREMENTS:	Hight
SUMMER RUNOFF:	Low
ECONOMIC DEVELOPMENT:	Fast
POWER:	Chaos, slowdown, confusion and "overexploitation"

Fig 7.8. *Table of secular problems related to water use in Spain*

Some very significant examples help us to understand the difficulty and complexity of water use in Spain, and especially, the huge volume of water needed on an annual basis.

Figure 7.9 presents these examples; in the first one, we can see (Moreno 1982) how in Spain, the irrigatable area which is actually irrigated, is double that of the world average. The need for water for irrigation is so widespread in our country that this doubles the global average.

	WORLD	SPAIN
FARMED AREA	4.000 M ha	21 M ha
IRRIGATABLE AREA	1.000 M ha	5 M ha
IRRIGATED AREA	250 M ha (25%)	2.5 M ha (55%)

	FRANCE	SPAIN
TOTAL USES (1975)	15 km^3	25 km^3
AGRICULTURAL USES	5.2 km^3	21.5 km^3
TOTAL RUNOFF	180 km^3	110 km^3
STORAGE CAPACITY	7 km^3	40 km^3

Fig. 7.9. *Comparisons of water uses in Spain and in France and frequency of Spanish irrigation, with some worldwide figures.*

In the second case, some very general global comparisons are made between water uses and yields in Spain and France.

France, with a larger surface area and more developed than Spain, present much lower total water uses, and the yields from French rivers, however, are substantially greater than those of Spanish ones.

In this context, France consumes 25% of the water used by Spain for irrigation, which is what is most difficult to satisfy, given that the demand for water occurs in summer, while the yields are generated at the humid times of year.

This means that Spain's water resources system is insufficient in certain years, with over 40 km^3 storage capacity, the French system is very sufficient, with only 7 km^3.

Table 7.3 provides details of the total annual yields, net consumption once returns have been discounted, and the relationship between net consumption and total yields.
The consumption of 20% of total renewable water resources is considered as the overexploitation limit of a system (Falkenmark and Lindh 1976). According to this criterion, and taking mean annual yields as total resources, most of the catchments surpass this overexploitation limit.

In short, it could be said that in Spain, water resources are overused in most of the catchments and that it is mainly the priority use of agriculture that not only requires very large volumes, but requires them at times of year in which the hydrological cycle does not provide them, and a well developed system of water resources is therefore needed to deal with these needs.

A country of these characteristics is very sensitive to possible decreases in water resources inherent to climate change.

Table 7.3. *Annual yields and consumption*

shpere	yields hm^3	consumption hm^3	relationship %
Norte III	5.614	98	2
Galicia Costa	12.245	479	4
Norte II	14.405	145	1
Norte I	13.147	403	3
Ebro	18.647	5.361	**29**
Tajo	11.371	(1) 2.328	**20**
Duero	14.175	2.929	**21**
C.I. Catalonia	2.728	493	18
Guadiana II	1.053	121	11
Guadalquivir	9.090	2.636	**29**
Balearic Isles	696	171	**25**
Sur	2.359	912	**39**
Guadiana I	4.624	1.756	**38**
Júcar	3.335	1.958	**59**
Canary Isles	394	244	**62**
Segura	(1) 1.411	1.350	**96**
Spain	113.998	20.613	18

(1) The nominal value of 600 hm^3 from the ATS was taken

Source: White paper on Water in Spain, Environment Ministry (1998)

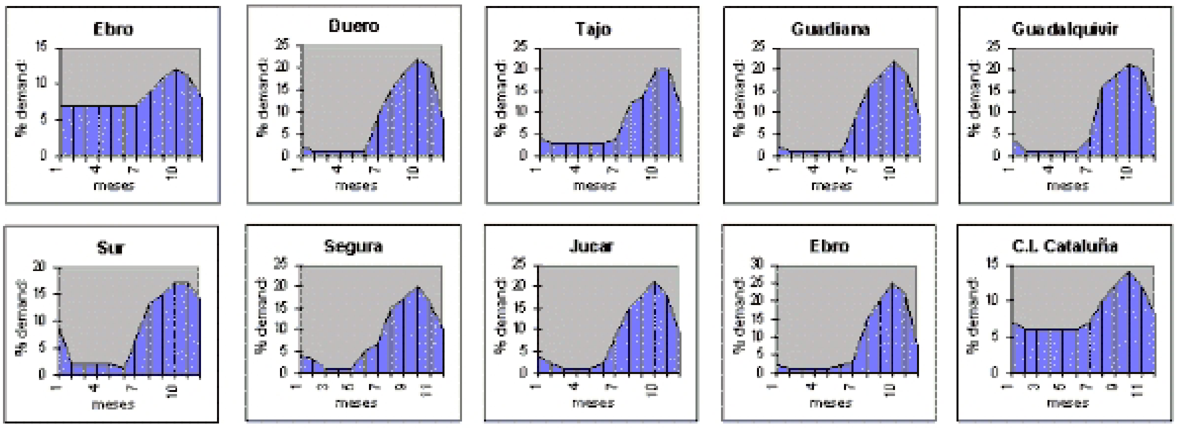
7.1.5. The resources-demands binomial; water resources regulation and systems

Satisfying water needs in relation to quantity, quality, space and time, involves availing of a water resources system, in order to adjust yields to demand structure. The temporal structure of these yields is conditioned by the hydrological cycle and demands, the structure of which is established by the different water uses and applications.

Hydric resources in Spain are generally low for the times of year in question. It should suffice to point out that, of the 110,000 hm^3 making up total annual runoff, only around 10,000 flow in rivers in the summer months, in which agricultural uses require over 24.000 hm^3.

Figure 7.10 represents the percentage distribution of demand, in the different Spanish catchments, along with the heterogeneity and lack of regularity of these.

Cuenca	Oct.	Nov.	Dic.	Ene.	Feb.	Mar.	Abr.	May.	Jun.	Jul.	Ago.	Sep.	
Norte	7	7	7	7	7	7	7	9	11	12	11	8	100
Duero	2	1	1	1	1	1	9	15	19	22	20	8	100
Tajo	4	3	3	3	3	3	4	12	14	20	20	11	100
Guadiana	2	1	1	1	1	1	8	16	19	22	19	9	100
Guadalquivir	4	1	1	1	1	1	4	16	19	21	20	11	100
Sur	9	2	2	2	2	1	6	13	15	17	17	14	100
Segura	4	3	1	1	1	5	7	15	17	20	16	10	100
Jucar	4	2	1	1	1	2	8	15	16	21	18	9	100
Ebro	2	1	1	1	1	2	3	15	20	25	22	7	100
C.I. Cataluña	7	6	6	6	6	6	7	10	12	14	12	8	100



* Meses de octubre a septiembre

Fig. 7.10. *Percentage distribution of demand in different Spanish catchments*

There are catchments such as Ebro, Guadalquivir and Guadiana 90% of whose needs are concentrated from May to September.

It appears that this pattern of temporal heterogeneity can only be exacerbated in view of the heterogeneous distribution of rainfall presented with climate change.

In short, regulation in Spain aimed at satisfying hydric requirements is very difficult, and climate change is expected to worsen the situation.

7.2. SENSITIVITY TO THE PRESENT CLIMATE

7.2.1 Relationships between climate, soil, land uses and yield. Runoff rates

As has already been pointed out, the generation of yields is based on the relationship between the binomial climate and surface (soil and cover). The soil's capacity to retain water, and the capacity of this to be used by plants, involves rainfall, or part of it, being retained and evapotranspired by plants. The reserve of water that can be used by plants, which is a function of the field capacity, permanent wilting point, apparent density and mean root depth, incorporates rainfall and returns water to the atmosphere by evapotranspiration in a continuous manner, filling up and emptying, depending on whether inputs or outputs are greater, until a point is reached at which the soil does not absorb any more water, the reserve fills up and runoff or recharge of aquifers is generated by the surpluses. The characteristics of the vegetation also determine the exchanges of water and energy, not only as a result of root depth, but also of aerial biomass and aerodynamic roughness.

The runoff rate of a catchment, understood as the relationship between the yield or runoff measured in a catchment and the total volume of rainfall that has fallen therein, varies as a consequence, and is lower with less rainfall and greater potential evapotranspiration, inherent to a temperature increase. The runoff coefficient also increases, in the same climatic conditions, with certain characteristics of the soil or the vegetation, which reduce returns to the atmosphere, such as less soil's thickness, less field capacity, or also less mean root depth, aerial biomass or aerodynamic roughness.

7.2.2. Study of unitary sensitivity. Influence on the yield of the unitary variations of mean temperature and annual rainfall.

Purely for purposes for theoretical orientation, procedures can be sought for estimating the sensitivity of the yield to unitary variations in the parameters of climate change, rainfall and temperature.

This was used to calculate runoff, using the Turc method, for annual rainfall values of between 200 and 900 mm and annual mean daily temperature of between 10º C and 30º C.

The tables of figure 7.11 represent the percentage decreases in the yield between the aforementioned ranges of values of rainfall and temperature, for the following hypotheses:

Temperature increase by 1º C
Temperature increase by 2,5º C
Decrease in rainfall by 10%
Temperature increase by 1º C and decrease in rainfall by 10%

Simple analysis of the table shows that sensitivity is very high, precisely in the areas with high mean temperatures and low rainfall. That is to say, in the areas of Spain with higher rainfall and average temperatures, the decreases in yields in the scenarios proposed reach values almost always below 4% or 5%.

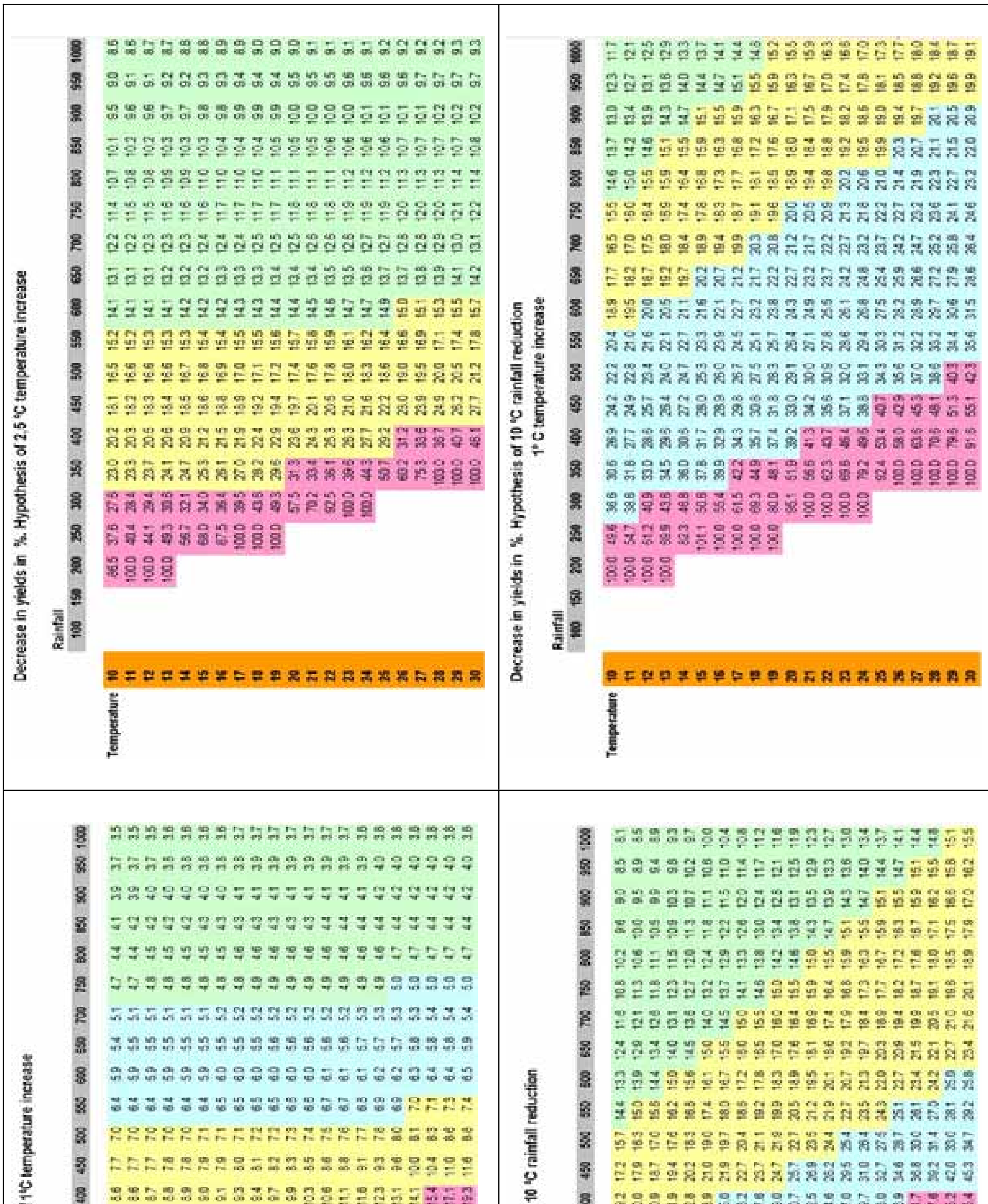


Fig. 7. 11*. Decrease in yields with hypotheses of different of temperature increase and reduced rainfall*

In the most critical areas, however, which could be classified as semiarid, with rainfall between 200 and 400 mm and annual mean daily temperatures of between 18 and 20ºC, the decreases in yields may be so serious that they could reduce the potential resources of the area by half.

In Spain, there are many areas with scarce rainfall and high temperatures, which determines a high level of sensitivity, in general terms, to the climate changes studied.

This type of calculation is purely orientational, used for analysing sensitivity, but they can be very useful for considering different scenarios.

7.2.3 Sensitivity to seasonal variations in rainfall and temperature

Water resources are not generated at one specific moment in time, and neither are they regular throughout the year. There are periods in which generation is possible, depending on temperatures and rainfall, and on soil saturation, among other factors.

Thus, the temporality of rainfall and temperatures has a greater effect on the generation of water resources, on many occasions, than the values of these two climatic parameters themselves.

In general terms and for most of Spain, water resources are generated in the coldest months or during those with the highest rainfall, provided that temperatures have not risen excessively. That is to say, in summer with high temperatures and evapotranspiration rates, most of the water the ground can retain is used by plants. The soil is dry, with a low saturation level, and no significant recharge or runoff occurs. In the cold months, evapotranspiration is very low and demand for water by plants is also very low, whereas excess yields saturate the soil and surpluses occur.

If temperatures only increase in summer, the volume of runoff will probably not decrease appreciably, as there will be no runoff either before or after the possible climatic change. The same reasoning is valid if we consider decreases in rainfall, but only for the summer months; it would make no difference in relation to water generation, unless there was a more accentuated water deficit resulting from irrigation.

The lack of knowledge of monthly distributions of rainfall and temperature prevents us from making orientational calculations. At a conceptual level, however, it could be said that the generation of water resources is qualitatively more sensitive to the way in which rainfall and temperatures are distributed throughout the year.

7.2.4 Sensitivity to external events; droughts and flooding

Assuming that changes in rainfall and in temperature were practically linear, an increase in temperature and a decrease in rainfall would combine to increase the frequency and severity of hydrological droughts. The increased demand for evapotranspiration related to warming would cause an increase in returns to the atmosphere, along with previous drier conditions of the soils during rainfall events, and a decrease in runoff and recharge of aquifers, along with reduced water quality, due to lower dilution. An increase in the frequency and severity of droughts in the last decade has been observed in some parts of the world, particularly in Africa and Asia. Furthermore, climatic models predict an increase in the frequency of drought for the near future, above all in medium-altitude areas (IPCC 2001).

Floods and inundations, however, do not follow this relatively simple pattern. A rise in temperature and a slight decrease in rainfall would have little influence on the frequency and magnitude of the floods. There is evidence, however, that extreme rainfall events have shown a slight increase in the last few decades in different parts of the world (IPCC 2001) and in particular in some sectors of the Pyrenees (Beguería 2003). Climate models are unsuitable for predicting inundations, as they are incapable of simulating the events at a suitable temporal scale. An increase in extreme rainfall events is believed to be very likely, as a result of accelerated climatic activity. Furthermore, in places where a significant part of the precipitation takes the form of snow, an advance in the melting season can be expected, as a consequence of global warming, which could lead to changes in the magnitude of the floods if the melting season coincides with a period of heavier rainfall.

Lastly, we should point out a few possible indirect effects of climate change on the generation of floods and soil erosion. In a scenario of global warming and increased summertime drought, degradation of the plant cover can be expected, along with increasingly frequent forest fires. These conditions could represent an increase in the frequency and severity of floods and of phenomena of soil erosion in small catchments.

7.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

7.3.1. Introduction to Climate-Hydrology

A modification of temperature or rainfall as a result of climate change would affect the hydric resources of a territory because, in the long term, the renewable resources of this are equal to the difference between rainfall and evapotranspiration.

If, in accordance with the climate models available for Spain, there is a slight decrease in annual rainfall and temperatures rise, there will be a future decrease in water resources.

Furthermore, the tendencies projected for Spain indicate greater temporal irregularity of precipitation, which would have negative consequences for the flood regime and for river regulation.

Not only are the quantitative aspects of water affected a change in climate, and a decrease in water quality can be accentuated along with a decrease in the amount of water. A lower volume of water available would cause water quality to fall and a drop in piezometic levels in aquifers, which would facilitate saltwater intrusion in coastal areas, which has also been favoured by the rise in sea level.

Some physical-chemical and biological processes in water depend on temperature, like, for example, blooms of algae, which would increase with temperature, thus producing greater oxygen consumption during decomposition. All of this can affect water quality in reservoirs, which would also be affected by the reduced oxygen concentrations and by reduced yields.

7.3.2. Definition of scenarios for defining impacts on water resources

7.3.2.1. Introduction

A scenario is defined as a plausible representation of a variable or set of variables in the future (world population, industrial activity, CO_2 emission, average sea level, temperature, precipitation, etc.), which can be based on different suppositions or on historic evolutions. Thus, a climate scenario is defined as a plausible representation of future climate (fundamentally related to the temperature and precipitation variables), which can also be based on other scenarios.

Given that there are numerous uncertainties related to the multiple factors regulating the behaviour of the climate system, it is not recommendable to use a climate scenario as if it were a short-term weather forecast. In this situation, it is advisable to represent future climate with the use of a range of projections covering a broad spectrum of uncertainties.

7.3.2.2. Types of scenarios

The climate scenarios used to evaluate the impact of a climate change on water resources are designed taking into account scocioeconomic aspects, and those related to land uses, environment or emissions, and they provide foreseeable changes in the variables intervening in the hydrological cycle. The ones most studied are temperature and rainfall, although other variables, such as solar radiation, wind speed or relative humidity can also be of great interest.

For evaluations of impacts on water resources, three different types of methodologies are used to define climate scenarios.

- *Incremental or synthetic scenarios* are simple adjustments of the reference climate (present climate), adapted to future climate changes on simples (increase by 1º or 5º in temperature, decrease by 5% or 10% in precipitation, etc…). These scenarios are occasionally based on the results of the scenarios produced by the *Modelos de Circulación General Acoplados Océano-Atmósfera* – ocean-atmosphere coupled general circulation models - (MCGA-OA).

- *Analogous scenarios* are the analogous representation of a climate that has undergone changes, based on previous records or on records from other regions.

- *The scenarios by the Ocean-Atmosphere Coupled General Circulation Models (OA-CGCM).* These are the most used ones at present and those that present the highest degree of reliability. They generate climate scenarios that indicate variations in relation to a reference climate, initially based on regional climate observations made by the Climate Research Unit, CRU, of the University of East Anglia in the United Kingdom, during the period 1961-1990. At present, these studies used for defining the reference climate have been extended to the 1900 – 1990 period.

7.3.2.3. Climate change scenarios for Spain

Figures 7.12 and 7.13 show the seasonal variations in temperature and rainfall obtained for Spain with 7 MCGA-OA models from different research institutes in different countries. For half way through the XXI century, these models project warming in Spain of between 1.0 and 5.0 °C and a decrease in rainfall of up to 40 mm in summer months.

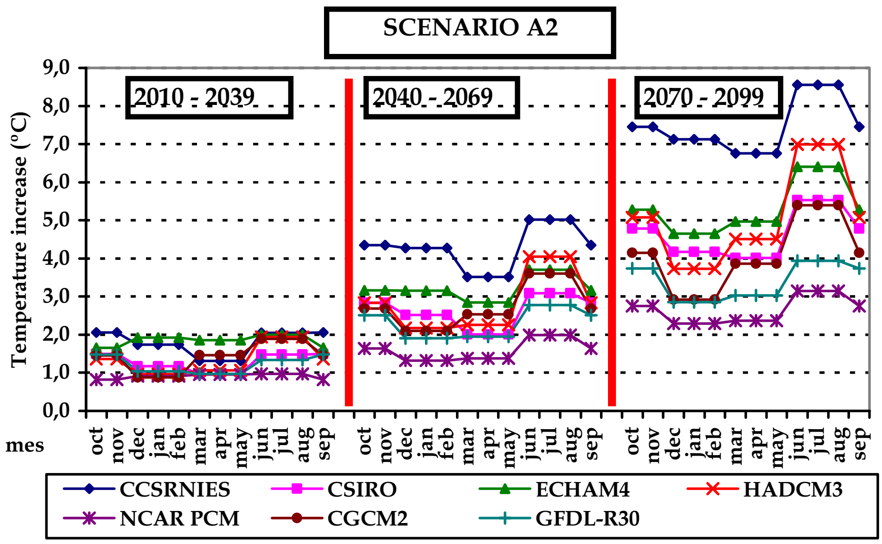


Fig. 7.12. *Temperature increase scenario A2 (IPPC).*

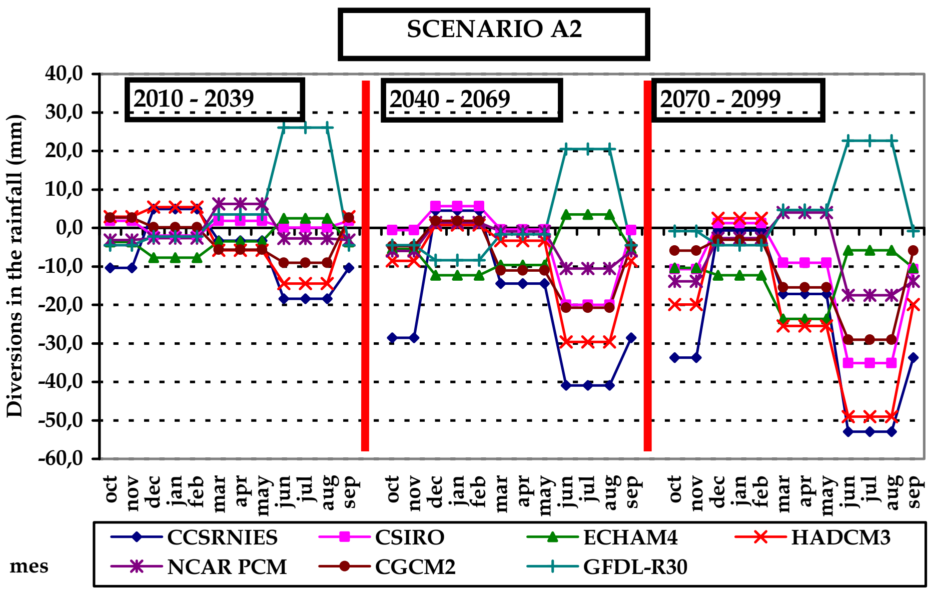


Fig. 7.13. *Variation in rainfall scenarios A2 (IPPC).*

The results of temperatures on the Iberian Peninsula, based on these global models, represent variations that are always positive, whereas in the case of rainfall, these variations are moderate and move in both directions.

One of the best known OA-CGCM models is model UKMO (United Kingdom Meteorological Model from the Hadley Centre for Climate Research in Bracknell, United Kingdom), which is a model that uses cells with a horizontal resolution of 2.5ºC x 3.75ºC in latitude-longitude (on the Iberian Peninsula it corresponds to cells of 280 km wide by 320 km high; see attached figure).

Fig. 7.14. *Diagram of the cells of UKMO model for Spain.*

The data used by this model come from two scenarios of future climate: the climate with the present CO_2 conditions ($1xCO_2$) and the equivalent climate with double CO_2 conditions ($2xCO_2$). In both cases, they belong to the same time interval, from 2040 to 2049, which correspond to the ten years after which the CO_2 doubles in the second scenario.

The outputs of the UKMO model consist of the monthly measurements of each year of maximum temperature (°C), minimum temperature (°C), rainfall (mm), wind speed (m s^{-1}) and relative humidity (%).

These climate scenarios are characterised in Spain by a temperature increase on doubling the concentration of atmospheric CO_2. Rainfall, however, increases in some cases and decreases in others, with seasonal differences, and there is generally a decrease in rainfall during summer months and an increase during the rest of the year (see table 7.4).

Table 7.4. *Summary of the results of the UKMO general circulation model for Spain.*

CELDA	TMAX		TMIN (ºC)		TMED (ºC)		PRECIP (mm)		SRAD(MJ/m2)	
	1xCO2	2xCO2	1xCO2	2xCO2	1xCO2	2xCO2	1xCO2	2xCO2	1xCO2	2xCO2
2-2	22,6	26,5	11,5	15,1	17,0	20,8	347,1	402,9	7360,6	7079,1
2-3	18,8	22,6	8,7	12,1	13,8	17,4	749,7	853,8	6198,5	6170,5
2-4	14,1	17,4	7,0	9,8	10,6	13,6	1502,1	1502,7	4254,2	4492,9
3-2	19,2	23,6	8,3	12,1	13,8	17,8	594,0	528,0	6638,2	6684,6
3-3	14,8	19,2	5,5	9,0	10,1	14,1	950,7	860,4	5205,0	5702,4
3-4	12,7	16,1	5,5	8,5	9,1	12,3	833,4	662,1	4356,0	4843,6
4-2	19,5	22,7	17,0	20,1	18,2	21,4	118,8	94,5	8872,0	8472,6
4-3	17,7	21,4	8,1	11,7	12,9	16,6	345,0	345,3	6665,4	6478,6
4-4	12,9	17,0	5,6	8,9	9,2	12,9	1043,7	892,2	4200,1	4786,0

Valores medios del período 2040-2049

CELDA	TMAX		TMIN (ºC)		TMED (ºC)		PRECIP (mm)		SRAD(MJ/m2)	
	F-A	F/A	F-A	F/A	F-A	F/A	F-A	F/A	F-A	F/A
2-2	3,9	117,3	3,6	131,3	3,8	122,4	55,8	116,1	-281,5	96,2
2-3	3,8	120,2	3,4	139,1	3,6	126,1	104,1	113,9	-28,0	99,5
2-4	3,3	123,4	2,8	140,0	3,0	128,3	0,6	100,0	238,7	105,6
3-2	4,4	122,9	3,8	145,8	4,0	129,0	-66,0	88,9	46,4	100,7
3-3	4,4	129,7	3,5	163,6	4,0	139,6	-90,3	90,5	497,4	109,6
3-4	3,4	126,8	3,0	154,5	3,2	135,2	-171,3	79,4	487,6	111,2
4-2	3,2	116,4	3,1	118,2	3,2	117,6	-24,3	79,5	-399,4	95,5
4-3	3,7	120,9	3,6	144,4	3,7	128,7	0,3	100,1	-186,8	97,2
4-4	4,1	131,8	3,3	158,9	3,7	140,2	-151,5	85,5	585,9	113,9

Diferencia (F-A) y relación (F/A) entre clima con doble (F) y simple (A) CO2

Although with the knowledge currently available, the OA-CGCM do not project a sufficiently accurate response of the climate systems to a variation in concentrations of atmospheric CO_2 and other GGs (greenhouse gasses), they are, however, the only tools available for obtaining patterns of climate response to different exogenous influences, and for this reason, increasingly accurate methods and processes are being developed in order to incorporate them into the existing ones. Most of these models solve similar equations, but there are differences with regard to temporal resolution, the physics of interconnections, treatment of clouds, representation of the ocean, etc., which accounts for some of the discrepancies in their results.

In order to answer questions about the impacts of a possible climate change on the water resources of a territory, increasingly greater temporal and spatial resolutions are needed, along with information on a higher number of variables (evapotranspiration, maximum and minimum temperatures, runoff, etc.), and it does not seem reasonable to demand this from the OA-CGCM. This is why regional climate models are being designed.

The PROMES model (Mesoscale Prognosis) is a regional model of primitive equations, hydrostatic and completely comprehensible. PROMES comes from the output fields of the GCM of the Hadley Centre for Climate Prediction and Research, known as HadCM2.

The basic objective of the regional climate model PROMES is to generate the necessary atmospheric fields to be uses as an input for the different models simulating hydric resources or for some other specific arda, both for current climate conditions (1xCO_2) and for a climate scenario considering a carbon dioxide concentration in the atmosphere which is double the existing one (2xCO_2).

The 1xCO_2 simulation took 10 years, which is a compromise between the convenience of 30-year simulations (time period considered ideal for characterising a climate) and available calculation resources.

The horizontal resolution used is uniform, and all the cells horizontal dimensions of $\Delta_x = \Delta_y =$ 50 km. The simulation region for Spain comprises 45x39 cells, including the border ones (figure 7.15).

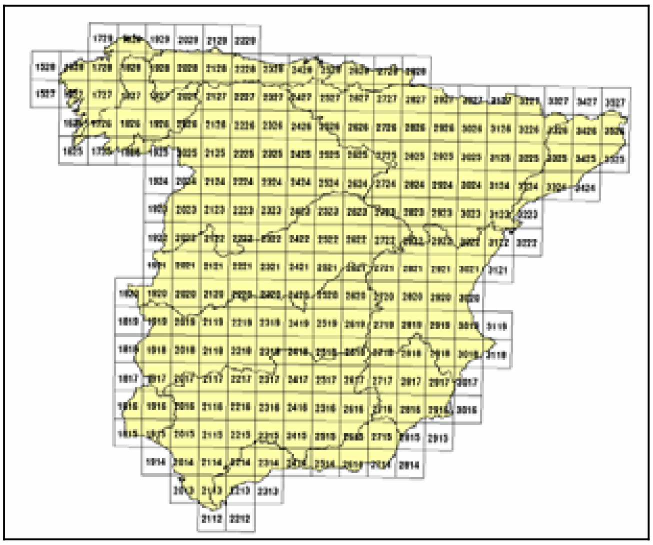


Fig. 7.15. *Calculation cells of the PROMES model.*

The CEDEX (1998) carried out a study to research the effects of climate change on water resources and water demand, in which the PROMES model was used to simulate climate scenarios. Figure 16 shows the mean daily temperatures in autumn simulated with PROMES for scenarios 1 x CO2 and 2 x CO2.

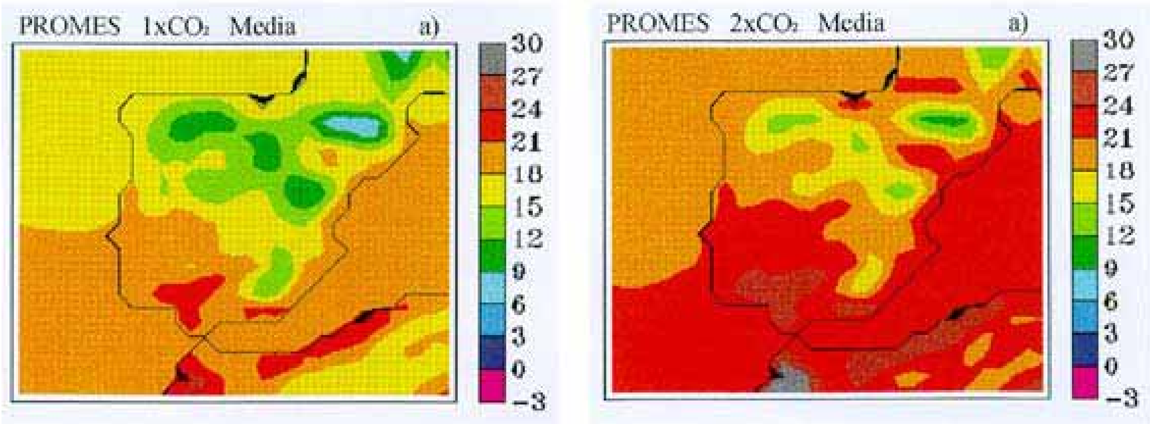


Fig. 7.16. *mean daily temperature at 2m in autumn: left). Simulation average 1 x CO2 PROMES, right). Simulation average 2 x CO2 PROMES (taken from CEDEX 1998).*

This study compared climate simulations generated by the PROMES model with those corresponding to the CRU climatology (Climate Research Unit) (Hulme et, al 1995), and concluded that the rainfall values of simulation $1xCO_2$ (present situation) are generally higher than the results obtained for the CRU climatological unit (1998). The difference in rainfall, is more relevant in mountain areas. With regard to temperature in scenario $1xCO_2$ in most regions of the Peninsula, these are higher than the results obtained by the CRU climatological unit (1998), varying from 1 to 3 degrees centigrade.

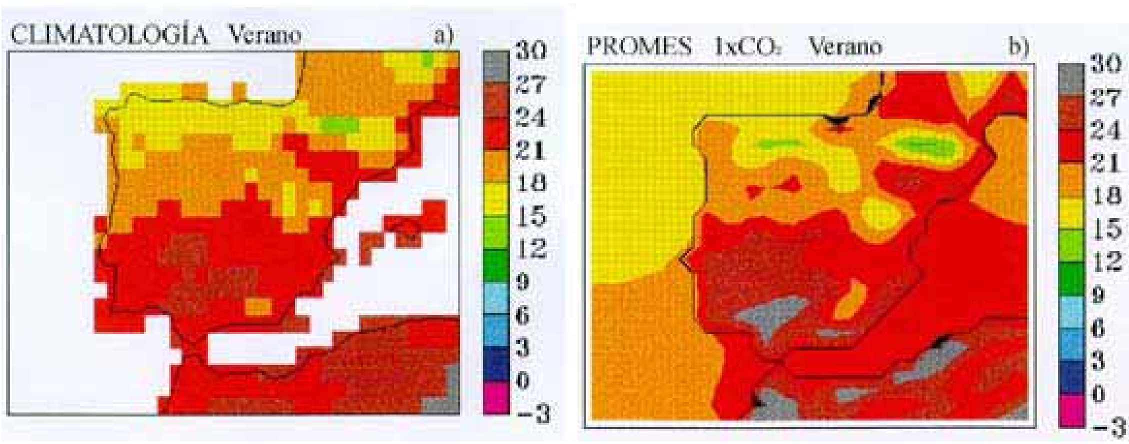


Fig. 7.17. Mean daily temperature at 2 m altitude in summer, a) CRU climatology, b) Simulation 1 x CO2 PROMES (taken from CEDEX 1998).

In general, PROMES overestimates both rainfall and temperature in the present situation, and the values for the future situation ($2xCO_2$) will probably also be overestimated. The remaining values used in the studies by the CEDEX, such as relative humidity, wind and radiation, were not contrasted, but there is evidence that greater uncertainty exists for these than for temperature and rainfall.

7.3.3. Evaluation of impacts on water resources in Spain

7.3.3.1. Introduction

The ACACIA Report by the European Commission on the Impacts of Climatic Change (1999) assumes for Europe that:

- The present and future pressures on water resources and on the management of these will be exacerbated by climate change (partly because the effects are uncertain). The risk of flooding will probably increase, and an increase in water scarcity is predicted, particularly in southern Europe. Climate change will probably exaggerate the differences in water resources between northern and southern Europe.
- In coastal areas, there will be a substantial increase in the risk of flooding, erosion and loss of wetlands, with implications for human colonisation, industry, tourism, agriculture and coastal natural habitats. Southern Europe seems to be more vulnerable to these changes.
- In mountain areas, the higher temperatures will cause the border between biotic and cryospheric zones to rise in altitude, thus disturbing the hydrological cycle. There will be a redistribution of species with risk of extinction in some cases

These conclusions by he ACACIA Report highlight the need to quantify the effects of climate change on water resources in Spain. The evaluation of these impacts in our country has followed different lines of work, in relation both to the temporal and spatial scale of the hydrological simulation and to the origin of the climate scenarios used. A description is now given of the different evaluations, arranged a lower to a higher degree of complexity of the modelling used.

7.3.3.2. Regional aggregated models

Given that an initial step involves long-term knowledge of the mean values of the main hydrological variables, application of regional laws expressing in annual averages rainfall, potential evapotranspiration (function of temperature) and total runoff, could provide a general view of the scope of the problem.

With this approach Ayala and Iglesias (Ayala-Carcedo et.al 2001), use an aggregated model for each of the big catchments into which Spain is divided, based on the use of annual regional laws. With regard to scenarios of climate change, they consider the predicted changes in relation to mean annual rainfall and temperature, provided by the National Meteorology Institute in 1995, based on the model Hadley Center (UK) from 1990, in which, on the 2060 horizon, mean annual temperature will rise by 2.5^{0}C and mean annual rainfall will decrease on the Peninsula by 8%.

These authors estimate that climate change will cause a global reduction of water resources by 17%, along with an increase in the interannual variability thereof, for the year 2060 (mean project horizon for big waterworks) and that these changes will be greater in the southern half of Spain. In order to obtain these values, a lumped conceptual model was applied, and the 1940-85 was used as a base.

7.3.3.3. Regional distributed models

Subsequently, the White Paper on Water in Spain (MIMAM 2000) maintained the approach related to the application of regional laws, but using a model distributed in space. Thus, a substantial improvement is attained of the results, on introducing the spatial variability of both rainfall and temperatures and of the physiographic features of the catchment.

The impact on the mean annual runoff derived from the different climate scenarios was estimated in MIMAM(2000) by means of the application, in a distributed fashion (1 km x 1 km cells), of Budyko's regional law (1961), which related runoff (A) with precipitation (P) and potential evapotranspiration (PET). This law had already been used in an experimental analysis applied to Spanish catchments with different climatic and hydrological features (Estrela *et al*. 1995). Previous to application, MIMAM (2000) contrasted the adjustment of this law to the data observed at 130 gauging points distributed throughout Spain (figure 7.18).

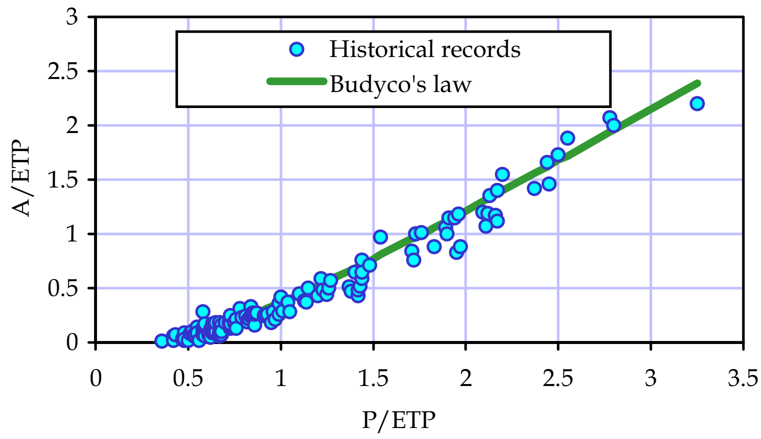


Fig. 7.18. *Relationships between yield, precipitation and PET at the gauging points (adapted from MIMAM 2000)*

The climate scenarios used in the White Paper on Water in Spain come from the climatic fields reflected in the document National Programme on Climate (MOPTMA 1995), which indicated that:

- A duplication of CO_2 could cause an increase in mean annual temperature, ranging from 1°C (analysis of response in transition) to 4°C (better estimate of the analysis of the response in balance), although these increases would be slightly greater in summer.
- There could be general decreases in the values of mean annual rainfall of between 5% and 15%, these being more likely in the southern half of the Peninsula. There may be a tendency towards temporal concentration of precipitation, along with greater annual and interannual variability.

Without ruling out the necessary precaution and uncertainties associated with the problem, the most likely evolution of the climate on the Spanish Peninsula, resulting from these analyses, was synthesised by MIMAM (2000) in the following temperature and precipitation scenarios, considered to be representative in the hypothesis of CO2 duplication, predicted for 2030.

1. Scenario 1. 1°C increase in mean annual temperature.
2. Scenario 2. 5% decrease in mean annual rainfall and a 1° C temperature increase.

3. Scenario 3. (unlikely extreme scenario) assuming a 15% decrease in mean annual rainfall and an extreme 4% temperature increase.

The most recent results related to rainfall on the Iberian Peninsula, based on global models, produce very moderate variations in precipitation, as our zone is situated in an area presenting a change of sign of the variation expected for precipitation, which means that in all the experiments, the line of zero change cuts across the Iberian Peninsula. This could imply more favourable hydrological conditions than the previously expounded ones.

From the analysis by MIMAM (2000) we can conclude that the catchments of Guadiana, Canarias, Segura, Júcar, Guadalquivir, Sur and Baleares (see figure 7.20), are those that would suffer the most severe impact on water resources. The climate scenarios (1 and 2) indicate an average decrease in water yields in Spain, in natural regime, of between 5 and 14%.

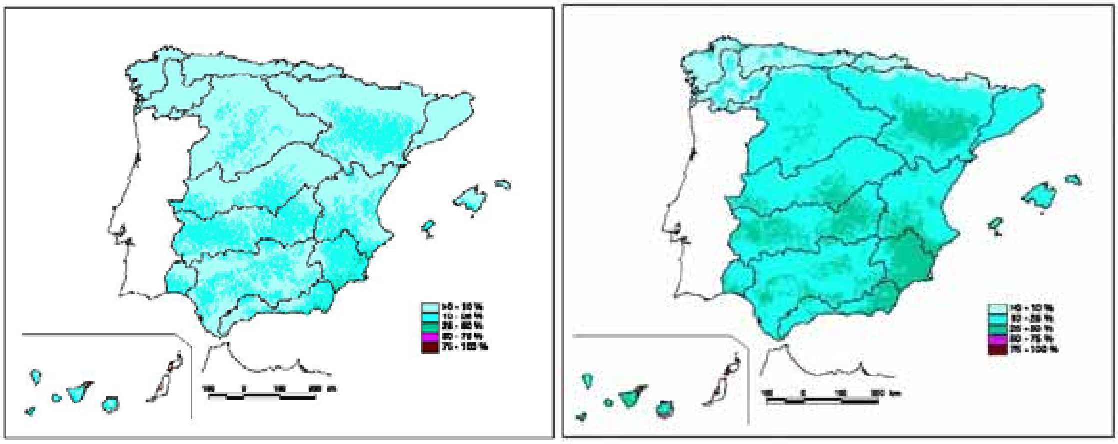


Fig. 7.19. *Map of percentage distribution of runoff for scenario 1 and in scenario 2*

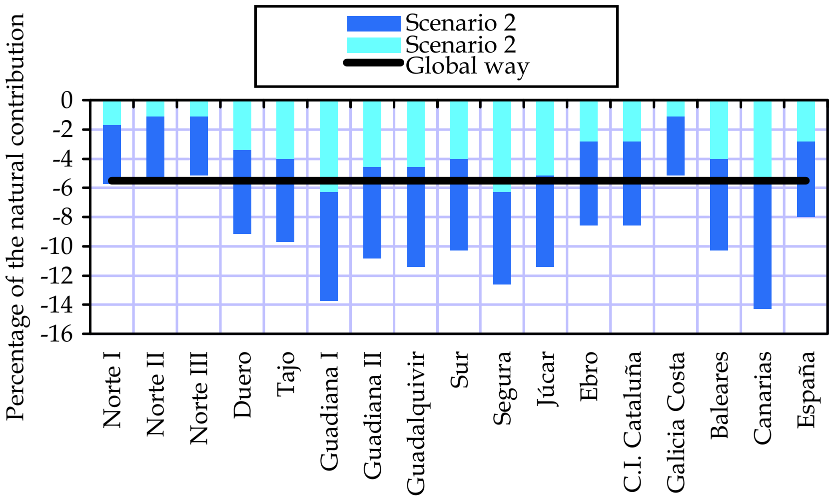


Fig. 7.20. *Percentages of decrease in total yields, for the climate scenarios considered, in long-term catchment management plans.*

7.3.3.4. Distributed models of simulation of the hydrological cycle

The distributed models of simulation of the hydrological cycle, such as the SIMPA model used in the White Paper on Water in Spain for the evaluation of hydric resources, establish hydric balances for the different processes taking place from the moment it rains until the waters runs off, whether on the surface or underground, and they estimate yields with the use of meteorological data (rainfall, potential evapotranspiration, etc.) and data on the physical characteristics of the territory (vegetation, hydrogeology, edaphology, etc.).

In this line of work, we should mention the studies carried out by the CEDEX's Centre of Hydrographic Studies (1998) or by Fernández (2002).

In the studies developed by the CEDEX in their "Study of the potential impact of climate change on water resources and demand for irrigation in determined regions of Spain" for the Environment Ministry (MIMAM 1998), three groups of climate scenarios were used for the hydrological simulations:

- Analysis of the sensitivity of climatic variations:
    - scenario 1. An increase by 1°C in mean annual temperature.
    - scenario 2. A decrease by 5% in mean annual rainfall and a 1° C temperature increase.
- General climate scenarios. From general circulation models, UKNMO model.
- Regional climate scenarios. Results of the PROMES regional climate model, considering increases in temperature and maintaining precipitation the same as at present.

Using the SIMPA (integrated system for modelling precipitation- yield) distribute rainfall-runoff model they obtained runoff maps for each scenario (see map corresponding to PROMES results in figure 7.21) and the percentage variables of runoff in relation to the present situation.

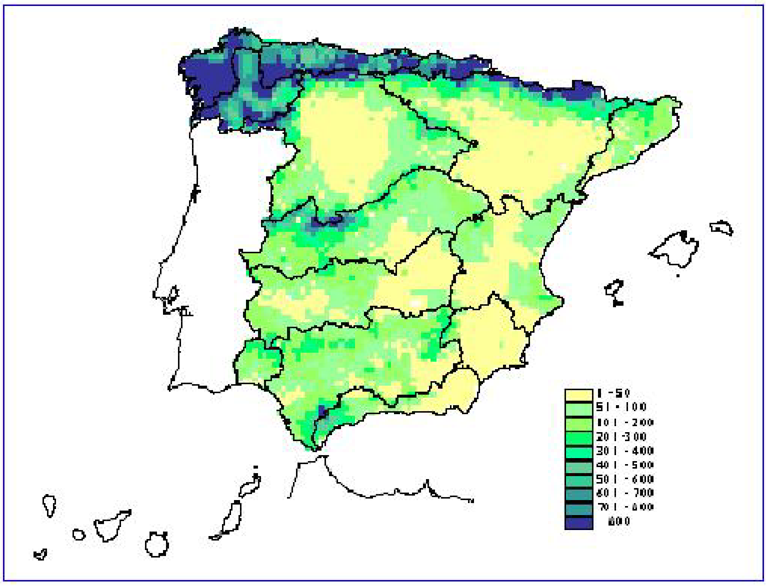


Fig. 7.21. *Map of total mean annual yield in mm, in the hypothesis of climate change resulting from the PROMES model.*

The analysis led to the following conclusions:

1) In Spain, there will be average decreases in total mean annual yield, ranging from 5% for scenario 1 to 14% for scenario 2 and regional scenario 3.
2) The Southeast of the Peninsula and the islands are the areas that will suffer the severest impacts on water resources. In scenario 1, the decrease in total yield will range from 2% (Galicia Costa and Norte I) and 11% (Guadiana and Segura), whereas in scenario 2, these percentages rise to 9% (Galicia Costa and Norte) and just over 25% (Canary Isles).
3) In the adopted regional scenario, total yield will range from 5% in Galicia Costa, and 22% in Guadiana II, with values similar to those of scenario 2, except in the Júcar catchment 15% compared with 20% for scenario 2, and the Catalonia internal catchments 20% compared with 15% for scenario 2.

The aforementioned study concludes that the results should not at all be taken as final, as these depend on the basic hypotheses adopted.

Fernández (2002), developed a methodological procedure to evaluate the impact on resources in Spain using hydrological modelling distributed at a monthly scale, together with the use of climatic fields created by regional models of climate change. He applied this procedure to 19 catchments distributed throughout Spain.

The future climate scenarios adopted were obtained by modifying the monthly precipitation and rainfall for the 1945 - 1995 period, with the difference in rainfall and temperature results obtained by the PROMES climate model in simulations $1xCO_2$ and $2xCO_2$ for the mean values of the 2040 – 2049 period.

This study also considers other simulations corresponding to different climate scenarios, such as those mentioned in MIMAM (2000) and others that they considered to be of interest. .A total of 15 hydrological simulations were made, presented in three main groups:

a) Nine annual simulations using Budyko's regional law (Schreiber *et al*. 1978) at annual scale.

b) Six monthly simulations using the distributed hydrological model SIMPA.

For the simulation at annual scale, use was made both of climatic fields (synthetic scenarios obtained by reducing precipitation in a set proportion and raising temperature by one or several degrees in relation to the base period) and scenarios generated by the PROMES model. In the simulations at monthly scale, climatic fields generated by the UKMO global climate model and by the PROMES regional climate model were used.

One of the important conclusions of this study lies in the significant differences obtained between the annual yields simulated with a model simulating monthly hydrological series over long time periods, such as SIMPA, and with the use of regional laws that only consider annual data or interannual averages, such as Budyko's. This discrepancy clearly shows that the simulations at annual scale are not appropriate for describing the variations in the yields caused by changes in rainfall and temperature, as they do not take into account the distribution of these throughout the year, a factor which, in the PROMES simulations used, has proven to be fundamental in the evaluation of the impact of climate change on water resources.

7.3.3.5. The impact of climate change on resources in catchment management.

Assessment studies of climate impact on water resources were not taken into account, in a specific manner, in the catchment management plans approved in Spain in the year 1998. The first time that this type of study was considered in certain detail was in the drafting of the Technical Documentation of the National Hydrological Plan (NHP). The complex question of water transfers between catchments required an evaluation of a possible decrease in water resources, due to climate change, in the catchments selected to yield resources.

The NHP considered the different reduction bounds in the yields obtained in the White Paper on Water (MIMAM 2000) for the different catchments, with an increase in the global recommended value, and the simultaneous introduction of an effect of greater irregularity in the values of the monthly series used. This was used for the possible catchments selected to yield resources, the Duero, Tajo and Ebro.

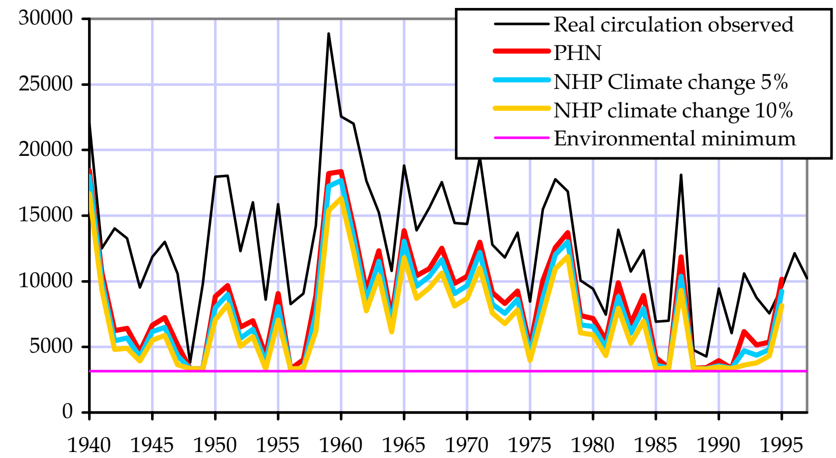


Fig. 7.22. *Circulation of annual flows (hm3) in the final section of the Ebro in suppositions of climate change.Hypothesis of 5 and 10% reduction. (taken from the DT of the NHP).*

In the case of the Ebro catchment, the bound corresponding to the two scenarios, according to the Spanish White Paper on Water, is between 3 and 9% of decreased yields.

Upon this basis, the analysis document of the Ebro system, drafted in the NHP, evaluated the annual flows in the lower section of the river in suppositions of 5 and 10% reductions of the water yields of the whole catchment.

As a result of this evaluation, figure 7.22, taken from the document *Systems Analysis* in the NHP, shows the circulation of annual flows really observed in the final section of the Ebro, together with the series of simulated circulation, adopted in the NHP, and the resulting circulations following a generalised 5 and 10% decrease in natural yields.

7.3.4. Integrated evaluation of the impacts of climate change on complex water resources systems

The methodological process for the integrated evaluation of the impacts of climate change on complex water resources systems requires the use of different sequentially nested simulation models. This is due to the high level of complexity and of interaction of the different elements making up the water resources systems, with regard to both their quantitative aspects and those related to the chemical and ecological quality of the water and to socioeconomic repercussions.

The sequential process is based on the selection of the results of the different climatological scenarios existing for Spain, both the ones provided by the Ocean-Atmosphere Coupled

General Circulation Models (OA-CGCM) and by the regional climate models providing these results with a higher degree of spatial detail. The climatological variables resulting from the models are the predicted variations in temperature and rainfall.

An important part of the evaluation of the impacts of climate change on water resources involves the selection of scenarios, among which are the incremental or synthetic ones, which can provide valuable information on the sensitivity of the system to future climate. The increments of these scenarios can sometimes be done taking as a guideline the results of the outputs of the General Circulation Models proposed by the IIPCC in its section on worldwide regionalisation, choosing those corresponding to Spain. Another way to evaluate water resources is using the scenarios of the regional models, whether these be HadCM2SUL, UKMO or PROMES, thus providing a wide range of scenarios, enabling the results of each one to be assessed at the precise moment, and permitting analysis of the results for different seasonal periods, in order to establish both global effects and those resulting from seasonal variations in rainfall and temperature and the possible effects of these on water resources.

Having selected the set of scenarios, the next methodological step involves simulating the hydrological cycle by means of a distributed rainfall-runoff model, encompassing the whole catchment at monthly temporal scale. This rainfall-runoff model would establish the place and proportion in which hydric resources would be reduced and to analyse how the different components and water storage would be affected, for instance, the piezometric levels of aquifers or the humidity of the soil in the upper layers (closely related to dry farming). Furthermore, if these models include the transport of certain chemical components dissolved in the water, it would be possible to evaluate the variations in chemical quality of the water resulting from climate change.

Having analysed the quantitative repercussions, and to a certain extent, the qualitative ones in catchments, the following process would consist of the simulation or optimisation of water resources management with the use of currently available models, such as SIMGES or OPTGES (Andreu *et al*. 1996). These models allow for the reproduction of water resources management and the evaluation of the guarantees or shortcomings occurring in urban and agricultural demand, and in ecological flows and environmental reserves set up within these systems. It is thus possible to establish the future effects of a decrease in hydric resources on the water resources system. Figure 7.23 shows the management simulation model for the Júcar system.

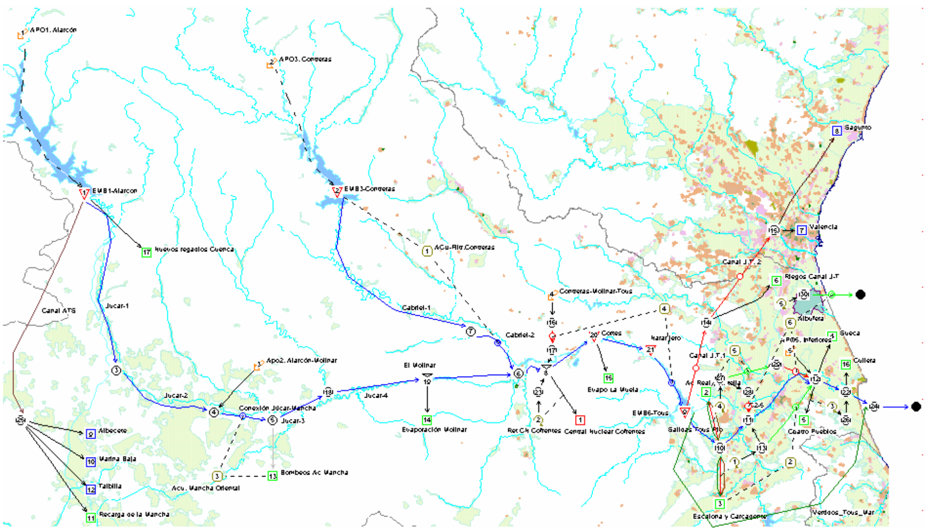


Fig. 7.23. *Management simulation model of the Júcar system.*

These models also incorporate an economic evaluation model, and a chemical and ecological quality management model, which include a model of dissolved oxygen, organic matter, conservative pollutants and of pollutants with first order decomposition. With the use of these models, the economic consequences can be established, along with the variations in water quality associated with the different management policies.

The integrated evaluation and detailed quantification of the impacts of climate change require the sequential use of different simulation models, which have been validated in recent years through day-to-day use in the spheres of both planning and management of catchments. Without the use of these tools, it is difficult to obtain objective detailed results, mainly due to the fact that the high number of simplifications necessary to deal with the problem could lead to unreal conclusions.

Garrote *et al*. (1999) evaluated the necessary increases in reservoir capacity resulting from the impacts of climate change. This study calculated the increased capacity needed in reservoirs to maintain the water resources system at the same level of current availability (1999), assuming scenarios involving a reduction of the series of yields caused by climate change.

These authors used the climate scenarios and the evaluation of water resources from the White Paper on Water in Spain. The climate scenarios used correspond to a mean annual temperature increase of between 1º C and 4º C and general decreases in mean annual rainfall values of between 5% and 15%.

Analysis of the necessary increase in regulation capacity in Spain was done with the use of the optimisation model of each one of the catchments in the spheres of planning on the Peninsula, using the OPTIGES programme. This model was used to estimate the maximum demand that can be satisfied at each node, fulfilling the following guarantee criterion, according to which, a failure is considered to exist in one of the following three situations:

1. Annual deficit of over 50% of annual demand.
2. Deficit for two consecutive years of over 75% of annual demand.
3. Deficit for 10 consecutive years of over 100% of annual demand.

In the scenario of moderate climate change, the reduction in yields on the Spanish Peninsula is by 5%, which is a reduction of 4% of the available resource. In the specific case of the Segura catchment, this decrease would reach 9%.

In the scenario of more severe change, the joint reduction of yields is 14%, with a decrease in the available resource of 11%. According to field of activity, Guadiana I is subjected to the greatest decrease in yields, with 24%. In the Segura catchment, however, there is a 22% decrease in yields, which constitutes the biggest decrease in available resources: 18%.

7.3.5. Impacts on the social and economic environment in relation to water resources.

Many of the Earth’s systems sustaining human societies are sensitive to climate and to the conditions of water resources, and will therefore suffer the impacts of changes thereof. Impacts can be expected in the circulation of oceans, sea level, water cycle, carbon and nutrient cycles, the productivity of natural ecosystems, agricultural productivity, pastures and forests and the behaviour, abundance and survival of plant and animal species, etc.

The changes in these systems in response to variation in water resources will affect human wellbeing, both positively and negatively. The impacts on human wellbeing will be felt through changes in water supply and demand, changes in the opportunities for using the environment for recreational purposes and tourism, consumption aside, changes regarding the “non-use” of

the water environment in relation to culture or preservation, changes related to the loss of property and lives resulting from extreme hydrological events, and changes in human health.
The impacts of climate change on water resources will affect perspectives for sustainable development in different parts of the world, and may lead to an increase in existing inequalities, because, as a general rule, the more arid countries are the ones most affected by these changes.

In some contexts, the impacts of climate change can cause social strife, economic decline and population displacements which could affect people's health. There may be substantial impacts on health, related to population displacement resulting from desertification processes, natural disasters or from environmental degradation.

The negative impacts of climate change will generally affected the more vulnerable, lower-income populations, predominantly in tropical and subtropical countries.

There are many specific conventional and advanced techniques that can contribute to improving the ordination and planning of the water environment, including instruments based on the market, aimed at combating pollution, demand management, environmental impact assessment, strategic environment plans, environmental auditing procedures and reports on the state of the environment.

An increase in the frequency and magnitude of extreme events could have adverse effects on all sectors and regions. Agriculture and water resources can be particularly vulnerable to changes in hydrological extremes and temperature changes. Floods can lead to the spread of disease transmitted by water and by vectors, in particular in developing countries. Much damage and financial loss caused by extreme events will have repercussions for a wide range of finance institutions, from insurance and reinsurance companies to investors, banks and funds for disaster aid. Changes in the statistics of extreme events have consequences for the design criteria of technical applications, which are based on probabilistic estimates.

Climate change can reduce water availability in certain regions subjected to hydric stress and increase it in others. In the municipal and industrial sectors, certain factors that do not depend on climate will probably have a great effect on water demand. Irrigation, however, is more conditioned by climate, and an increase or decrease in a determined zone depends on changes in precipitation. If temperatures are higher, there will be a greater demand for crops, resulting from evapotranspiration.

7.4. MOST VULNERABLE AREAS

7.4.1 Concept and criteria of vulnerability

The vulnerability of a territory to variations in hydric resources is closely related to the uses occurring therein. One same geographic space is more vulnerable when its water needs are greater, as with the guarantees it requires. A territory will be much more vulnerable, in equal conditions with regard to demand volume, if this volume is used for urban supply, as opposed to for irrigation, because in the latter case, the guarantees of supply are less demanding.

In general terms, the territories with greater "hydric stress" should be considered the most vulnerable to possible variations in water resources.

There are many indicators of hydric stress, most of these related to water demand and to renewable hydric resources. The following section shows two indicators of hydric stress for the whole of Spain: the deficits between consumer demand and potential resources and the so-called consumer index, calculated as the quotient between consumer demand and potential resource.

7.4.2. Vulnerability to variations in hydric resources in Spain

An indicator of the vulnerability of the different territories in Spain can be obtained by establishing the balance between the maps of potential resources and consumer demand.

Potential resource is understood as the non-reserved part of natural resources plus the resources from the desalinisation of seawater and the existing transfers.

The map of consumer demand can be obtained by applying to the demand for irrigation 80% and for urban and industrial demand, 90%, along a 10 km stretch along the coast of the Peninsula, 80% along the same stretch of coast on the islands and 20% in the rest of the territory, thus reflecting the different possibilities for direct or indirect reuse of resources.

These criteria were applied in the drafting of the White Paper on Water in Spain (MIMAM 2000), and a map of balances was obtained in each one of the resources systems in Spain's catchments. The balance, aggregated according to resources systems, presupposes the full use of the potential resources generated throughout the whole territory. as well as, where pertinent, resources from the desalinisation of seawater and from transfers from other systems. This represents a maximum level of use, which requires a series of infrastructures, along with the necessary quality conditions. Figure 7.24 shows the water resources system with a deficit.

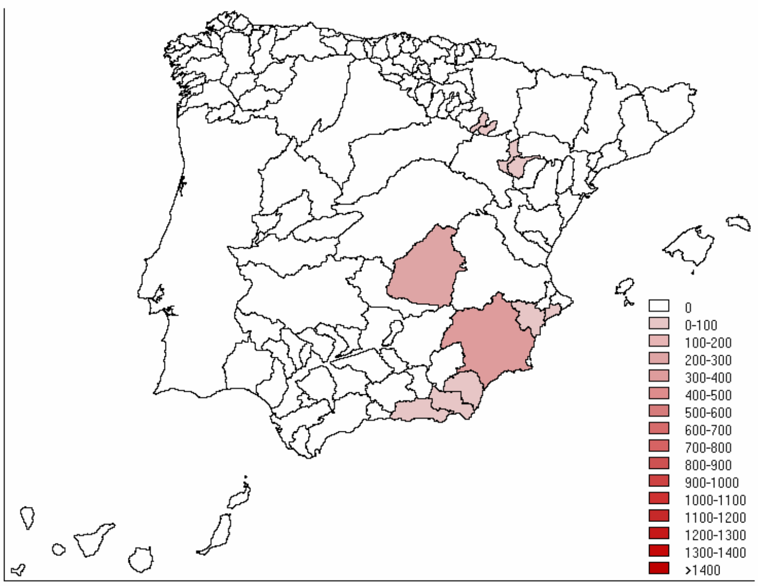


Fig. 7.24. *Deficit map (hm3/year) in the water resources system (taken from MIMAM 2000)*

The previous map shows that the deficits are located mainly in the Segura, the headwaters of the Guadiana, Vinalopó-Alacantí and Marina Baja in the Júcar, the east of the Sur catchment, together with other smaller systems on the right-hand bank of the Ebro. Although all these systems show a deficit, the magnitude of the problem is obviously very different, and the deficit of the systems on the right-hand bank of the Ebro, of great local importance, cannot be compared with that of the headwaters of the Guadiana or with the set of southern systems made up of the Júcar, the Segura and the eastern Sur systems, with a clearly greater territorial impact and dimension (MIMAM 2000).

This map can, however, give rise to erroneous interpretations, because, as we are dealing with absolute figures, these are conditioned by the size of the systems, which varies greatly from case to case. In order to avoid this, MIMAM (2000) designed the so-called consumption index, relating consumer demand to potential resources. This index is the basis of the following map of risk of scarcity, which could be a good indicator of the degree of vulnerability of the different water resource systems in Spain to variations in water resources. The most vulnerable ones are those classified as structurally scarce, followed to a lesser extent by those classified of momentary scarcity.

Figure 7.25 shows that the systems with a deficit suffer from a structural type of scarcity, that is to say, the potential resource, including reuse, desalinisation and transfers, is systematically lower than the consumption level to be reached. But there is also a series of systems which, although they present a surplus, run the risk of suffering a momentary type scarcity, due to the fact that their consumption levels are relatively close to the potential resource level. In these conditions, adverse hydrological sequences could cause supply problems due to insufficient resources.

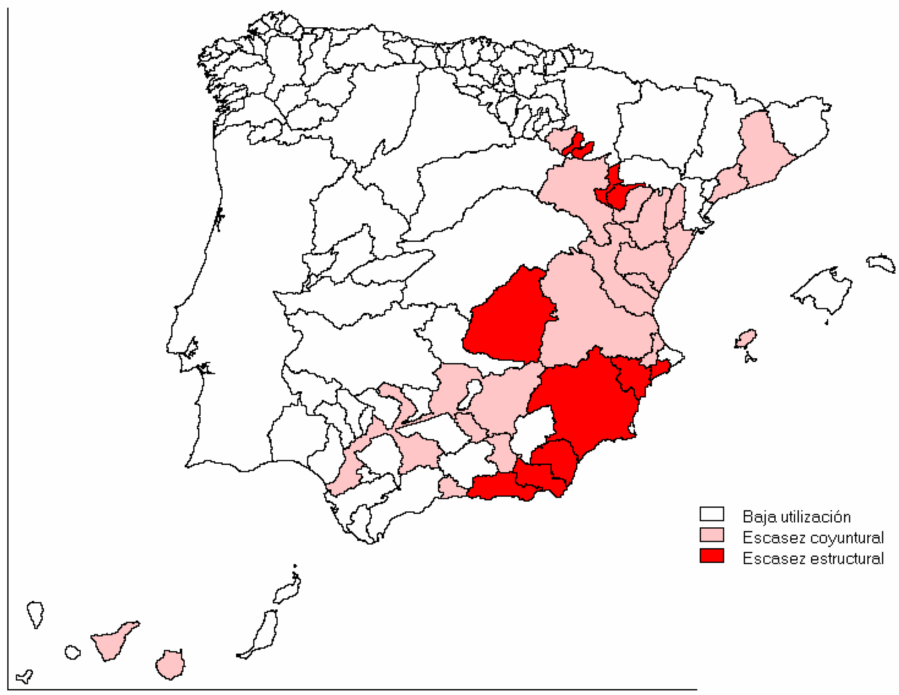


Fig. 7.25. *Map of risk of scarcity of the resource systems (taken from MIMAM 2000)*

As can be seen, a large part of the systems in the south-eastern half of the Peninsula, together with some systems on the right-hand bank of the Ebro, part of Catalonia and some islands, are subjected to a scarcity of resources of the structural or momentary type, even in the hypothetical case of maximum use of potential resources, including desalinisation and transfers and a maximum degree of reuse.

7.5. MAIN ADAPTIVE OPTIONS

7.5.1. Concepts and classification of the mitigatory effects of the decrease in water resources.

From the previous sections, we can highlight three main impacts of climate change on hydrological cycles: 1) global warming will cause an increase in water demand by terrestrial ecosystems and by agriculture systems 2) climate change will most likely cause a reduction of available water resources in most of the catchments, and 3) extreme events will most likely become accentuated: droughts and flooding.

In order to deal with this increased pressure on water resources systems, which are already above the overexploitation levels in most of the catchments, three types of adaptive options can be proposed (see, for example, MMA 1998): increased supply, demand management and improved systems management.

The first one is based both on traditional actions (increased reservoir volumes, transfers) and on alternatives which have not yet been sufficiently developed (groundwater) and on the development of unconventional resources (rainwater catchment, desalinisation, reuse). The second one is based on reducing consumption by means of different procedures, such as policies related to tariffs or subsidies (canalisation, irrigation). The third one lies in improving knowledge of climate and hydrological systems and perfecting and applying instruments for resources management, particularly for extreme conditions (droughts).

In any case, it is important that the actions undertaken do not undermine the sustainability of the system, and, in particular, that they are compatible with the Framework Directive on Water (WFD). The options proposed should be applied regardless of climate change in order to reduce overexploitation levels, to increase the resistance of the systems to extreme situations, and to facilitate the recovery of good ecological conditions. Climate change, seen in one of the main conclusions of the project ACACIA (Parry 2000), constitutes a serious challenge for the establishment of sustainable management of water resources.

In view of the obvious limitations of this document, we will attempt to write a synthetic review, placing more emphasis on the advantages and disadvantages of each one of them than on details of a technical nature.

7.5.2. Options for increasing resources

Available resources can be increased through the implementation of very different options, from those based on ancient techniques (rainwater catchment), to the more characteristic ones from half way through the XX century (reservoirs), the harnessing of storm waters, to techniques making use of the latest technology (desalinisation). The following are the main types, together with a critical analysis.

Reforestation

It has traditionally been considered that an increase in the area and density of forests i) reduces soil erosion, ii) reduces the frequency and intensity of floods, iii) improves surface and subterranean resources, and iv) even increases rainfall. However, experience accumulated during the XX century throughout the world in different environments and at different scales, has refuted these assumptions, or has subjected them to certain conditions (see summary in Gallart and Llorens 2003): i) improving plant cover reduces soil erosion, but on many occasions, the destruction of the pre-existing vegetation, work with machines and opening up new trails have counteracted this effect; ii) forest cover clearly reduces small or medium-magnitude floods in small catchments, but does not big floods in medium or large-sized catchments; iii) establishing forest cover in catchments with the use of short vegetation determines a reduction of surface and subterranean resources. The problem is a complex one, the disappearance of trees leads to an increase in yields during the first 2 or 3 years. On one hand, it increases canopy interception, but on the other, it improves the soil's capacity for storage and reduces evaporation from the soil; iv) increased forest cover causes an increase in real evapotranspiration, so that it can represent an increase in rainfall, but this effect does not compensate for the increase in evapotranspiration and only occurs at continental scale.

There is no doubt that there are many areas of Spain in which, for different reasons (abandonment of rural activities, overgrazing, fires...), the plant cover has become degraded, and requires actions aimed at regeneration. Furthermore, some of the strategies aimed at mitigating climate change are based on reforestation as a means of carbon sequestration, which is contemplated in the Kyoto protocol. The design of these actions, however, should take into account that certain environmental advantages are gained at the expense of hydrology.

The maintenance could also be recommended of plant cover in a limited number of areas in which environmental problems such as the risk of erosion are not very serious, in comparison with the interest in minimising evapotranspiration (aquifer recharge zones, catchment areas).

Catchment of rainwater or dew.

Since ancient times, different systems have been used to harness rainwater for small farms or to supply isolated dwellings or small communities. Most of these devices have now been abandoned in Spain for different technical, economic or cultural reasons. In recent years, however, these technologies are being recovered in different parts of the world, due to their low economic and environmental cost and the ease with which they can be implemented in remote areas. In 1991 the *International Rainwater Catchment Systems Association* (http://www.ircsa.org/) was created, an international association for scientific, technical and educational development. The UNEP is also lending great support to these technologies (UNEP 1998).

The main limitation of these techniques is the low level of supply guarantee, but they may be of use for improving reforestation techniques and favouring aquifer recharge, and they could be used alternatively with underground resources for promoting the recharge of aquifers during wet spells.

Increased storage capacity, transfers between catchments

One of the traditional options for dealing with a foreseeable decrease in resources and increased temporal variability thereof, involves increasing storage capacity or transferring resources from one catchment to another. It has been shown, however, that in the last few decades, the high socioeconomic and environmental costs of these structures are rarely offset by the benefits they produce (MMA,1998; WCD 2000). Besides, in Spain there is a record number of dams, and most of the rivers are already over-regulated. Since the FDW was adopted, the legal and environmental requirements for the construction of new dams are very restrictive in Europe (Barreira 2004).

*Groundwate*r

Groundwater plays a very important role in Spain. These currently irrigate approximately one third of the irrigated area, but they produce more than half of the income. Groundwater is the main source of supply for small communities and is a strategic resource in the event of drought.

Until 1985 groundwaters were not regulated, and were rapidly exploited by private individuals, which led to many cases of overexploitation. At present, over 20% of the hydrogeological units are overexploited (pumping rate similar to or greater than recharge). Pollution by nitrates or by intrusion of the marine salt wedge are the main quality problems of groundwater. Since 1985, with the enactment of the Water Law, groundwater is of public domain, but he Administration, due to a lack of financial, human and technical means, has been incapable, except on very few occasions, of controlling the excessive exploitation of aquifers or of establishing a functional joint system of management of surface and surface waters and groundwater.

Certain options for the exploitation of groundwater may be of great interest with regard to Climate Change. In particular, *alternative use* (utilisation of surface resources during wet periods and of the groundwater ones in dry periods), artificial recharge during wet periods or temporal overexploitation of certain aquifers, in particular, coastal ones, during periods of drought, are some of these (MMA 1998).

Desalinisation

Desalinisation has long existed in Spain, as it was first implemented in the Canary Isles in 1969. Great advances have been made in recent years with regard to desalinisation, especially from the point of view of economic cost. These technologies currently enable water resources to be obtained from seawater of low-quality water at a price which allows these resources to be used for certain types of high-performance irrigation. The main disadvantages are the high energy costs and the elimination of the resulting brine. A sustainable option would be the use of renewable energy to support desalinisation. There has been much experience in the Canary Isles involving large-scale desalinisation using aeolic energy aimed at reducing energy costs. The *Instituto Tecnológico de Canarias* – Canary Isles Technology Institute- (ITC) has developed several applications for the implementation of this type of studies and some small-scale experiences of totally autonomous systems with aeolic or solar energy.

Reuse

Direct reuse is understood as the direct use of purified wastewater , with a greater or lesser degree of previous treatment, by transport to the second point of use through a specific duct, with no intermediate dumping into public waterways.

The possibilities for reuse are conditioned by the availability of treated wastewaters, by the quality of these, and by the quality requirements for second use. Most reused water is for irrigation, and to a much lesser degree, for recreational use and golf courses, municipal, environmental and industrial uses. Use for drinking water is forbidden by law.

Directives for the regulation of water reuse not only consider minimum quality parameters for each use, but also methodologies and quality control criteria applied to analyses, surveillance systems and certain safety regulations aimed at reducing risks, such as limitation applied to sprinkle irrigation and storage and labelling of undrinkable water. There is an urgent need for regulations and directives at European and National level.

The main problems involve the uncertainty regarding the potential risk to public health (in particular with regard to the long-term recharge of aquifers), the high cost of the more intense purifying processes, and the fact that purified water is not returned to the natural waterways, it being necessary to establish ecological channels aimed at avoiding serious environmental aggression in dry areas (AEMA 2002).

7.5.3. Options for optimisation of use. Demand management.

The need to reduce the pressure on hydrological systems in order not to compromise the sustainability, along with the growing unavailability of water of sufficient quality is leading the water planners to focus increasingly on the possibilities of reducing demand. Some of the demand management options are now summarised (MMA 1998; AEMA 2002).

Public information and the use of simple techniques, such as those applied to the discharge of toilet cisterns, can generate reductions of up to 40% of urban consumption. The water supply in many cities, however, is in the hands of private companies, and water saving clashes with their interests.

Even without considering earnings, water metering systems cause a 10 – 25% reduction in consumption. Losses in the distribution networks tend to be considerable (average of 28%, with extreme cases in Spain of 50%) and depend on the age of the network. Reducing losses is a costly process and has a technical limit of between 10% and 15%.

Pricing policies are also a mechanism for controlling demand, especially when excessive consumption is penalised. Although prices very greatly according to users (domestic, industrial, agricultural), experience has shown that a price rise reduces consumption.

The main water consumer in Spain is irrigation. The current consumption rate is unsustainable, as this had led to the overexploitation of most of the catchments and of a growing number of aquifers, and to a reduction of the quality of surface water and groundwaters, mainly caused by nitrates and salts from soil leaching. The estimates of the NHP, of the National Irrigation Plan, and of the different Catchment Plans are political figures, with no realistic sustainability criteria, and less so with regard to CC. It will therefore be necessary to reduce growth estimates, even those related to the current area irrigated. It will also be necessary to substitute certain crops with a high hydrological cost (rice, corn) by other, less costly ones, and to stop irrigation of unsuitable land. We must ensure that the subsidy policies for agriculture are favourable for hydrological sustainability. Improvement of irrigation techniques and of the efficiency of transport networks can lead to considerable savings, although the economic costs are high and some of the highly efficient hydrological techniques are unsustainable because they cause soil salinisation.

In the industrial sector, suitable pricing policies and legal provisions are needed, in order to favour low-consumption, clean water technologies. Efficient control is needed of direct extraction, especially of groundwater, and of spills.

7.5.4. Options for the improvement and management of the water resources system.

These are actions aimed at obtaining more information on water resources systems and tools for more efficient management.

The metering networks of precipitation, meteorology, snow blanket, flows and piezometric levels should be improved in order to obtain more suitable information on the hydrological cycle. In particular, precipitation and meteorology are observed mainly in population nuclei instead of in the headwater areas, more relevant for the generation of resources, and the metering network in catchments in natural regime is clearly insufficient.

The simulation models of yields in natural regime should be improved in order to reproduce the hydric balance in as physical a way as possible, considering groundwater and differentiating between intercepted water and the water transpired by vegetation. Time should be considered on a daily basis, and the uncertainty of predictions should be considered in an explicit manner. The simulation and optimisation models of the water resources systems should be integrated into Decision-taking Support Systems for unspecialised users.

The databases of resources, demand and water resources systems should be updated as soon as possible and new technologies should be made available.

The creation of Exchange Centres of Water Use Rights, provided for by the Water Law, could improve water management, especially in conditions of scarcity, on favouring users' perception of water as a scarce commodity and favouring the recovery of costs provided for in the FDW (Moral *et al*. 2003).

Resource management during periods of drought should be given special mention. Firstly, improved methods need to be developed for early detection, for which updated information is required on rainfall, climate, soil humidity, flows, piezometric levels of aquifers and reserves in reservoirs. The use of long-term weather predictions, along with the possible correlation of drought periods with global indicators such as the North Atlantic Oscillations or the Niño, in the Pacific, should be studied and implemented in the detection system. In second place, it is necessary to establish plans of action in order to clearly establish the regulations for the exploitation of the system, groundwater resources in particular, for the different levels of risk or severity of drought.

Lastly, sustainable catchment management requires integrated water and territorial management. Any decision related to the territory involves a decision regarding the quantity and quality of water (Falkenmark 2000).

7.6. REPERCUSSIONS FOR OTHER SECTORS OR AREAS

7.6.1. Sectors of influence in the variation in water resources due to climate change

Variation in water resources as a consequence of possible climate change is conditioned by the influence of other sectors which are also affected by this change.

In theory, there are three sectors that affect or can affect water resources, and alterations in these sectors can therefore determine changes in the quantity and quality of water resources.

All sectors related to soil and plant cover can influence the generation of runoff, for example:

Forestry sector

An increase in forest masses reduces the intensity of floods and helps to establish greater temporal regularity in the generation of runoff.

Edaphic resources

The generation or destruction of soils conditions their retention capacity and therefore the amounts of water awaiting an evapotranspiration process. They also affect the intensity and temporal regularity of floods in the same way.

Plant biodiversity

Plant species, with their specific root depth, their water needs and the characteristics of the soils where they settle themselves, there determine the water balance and the generation of contributions

7.6.2. Repercussions of variation in water resources for other sectors

Changes in water resources in turn seriously affect many other sectors. There is a clear influence of water resources in the following eleven sectors:

Terrestrial ecosystems

The existence of flora, fauna and in general all living things is conditioned by the availability of water, of appropriate quality in each case. Variation in the quantity and quality of water resources and the spatial and temporal distribution of these, can condition the existence and development of terrestrial ecosystems.

Continental aquatic ecosystems

Humid areas contain a very rich and varied fauna in comparison with the surrounding areas, particularly in Spain. They depend on the bodies of water they are made up of and on the natural sources of supply of this. Spatial variability in the yield can also play an important role in relation to the movement of migratory birds.

Plant biodiversity

Plant biodiversity is governed by the presence of water, which is needed for the development of the different species of plants, and variations in yield can cause the disappearance of species or substitution by others with a better capacity for adaptation. This sector also has an influence on the generation of water resources.

Animal biodiversity

In an analogous way, animal biodiversity depends on the presence of water, which is needed to sustain the different animal species, and variations in yield can lead to the disappearance of species migration.

Agricultural sector

This sector is a vital one in Spain. Over 3 million ha are irrigated 2 with surface waters and 1 with groundwater. Irrigation is possible thanks to a generalised regulation process with reservoirs and aquifers. A decrease in rainfall would cause a reduction of resources for irrigation, which means that the use guarantee would be reduced. It would not be sufficient to improve regulation, given that this is already well developed and there is not much room for more improvement.

Forestry sector

This is another double input sector, affected by the amount and spatial distribution of the yield, and at the same time a conditioning factor of the generation process of water resources and very particularly of the amount and intensity of floods.

Natural risks of climatic origin

The spatial distribution of the foreseeably more heterogeneous yield resulting from climate change, and even the increased number and intensity of extreme events will probably exacerbate the problem of floods and will increase the frequency and intensity of landslides. This phenomenon, in spite of the great uncertainties involved, is of particular interest for study in Spain, given the secular nature of the risks for human life in floods and landslides.

Energy sector

The energy sector is conditioned by the existence of sufficient amounts of water, mainly for the production of hydroelectric energy, but also for covering the cooling needs of thermal and nuclear power plants. In spite of the existing high level of regulation, the hydroelectric sector will be affected by the foreseeable decrease in yields caused by climate change. Apart from these general aspects, it must be taken into account that a decrease in resources will require, for agriculture, a type of regulation adapted to its needs, with more irregular liberation of water of the reservoirs, which will affect the hydroelectric production subjected to more regularised demand.

Tourism sector

The tourism sector is governed by a very temporally heterogeneous type of demand, as with agriculture. The reduction of resources, and even more so, the worse distribution of these throughout the year, will be a factor affecting tourism. It is precisely in the Mediterranean areas, with little or no rain in summertime, those presenting the greatest demand for tourism, and these are the areas in which water resources can suffer the biggest percentage reductions as a result of climate change.

Human heath

The reduction of flows, much more accentuated in summer months, may affect parameters of water quality, with consequences for human health.

7.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

7.7.1. Analysis of uncertainties and the relative importance of these

In reference to the estimation of water resources in a possible climate change, we must consider both the uncertainties inherent in the estimation, by simulation, of temperature increases and reduced rainfall (in the case of Spain), and the uncertainties involved in the generation process of resources, which are influenced by soil and the plant cover, on one hand, and the water resources system and the way this is managed, on the other.

Of these two main groups of uncertainties, that is, databases and the runoff generation process, the former are of greater relevant importance, due to the fact that in calculations of resources generation, there are many methods that allow for appropriate contrasts of results.

7.7.2. Influence of databases. Scenarios.

The most relevant uncertainties refer to the projection of rainfall and temperature for the horizons of this century. These are the databases, and any calculation or estimate of runoff is based on this climatic parameters. It has also been seen that big variations in rainfall or temperature are not needed to cause big changes with regard to the reduction of runoff, especially with the semiarid climate type, unfortunately common in Spain.

Calculations of yields are made by means of sufficiently gauged hydrological studies, at least in Spain, and most specialists estimate that the admissible errors in a good study are 15%. However, to this end, reliable monthly data are needed, along with homogeneous and representative series and suitable distribution of the information at spatial level. The reliability of evaluations of resources in conditions of climate change will increase as the scenarios become more real, and provide more information on the temporal distribution of rainfall and temperature.

- Uncertainties in the databases
Increase in real temperature value
reduced rainfall
spatial distribution of both with the appropriate discretisation.

7.7.3 Spatial and temporal distribution of rainfall and temperature

The spatial discretisation of the simulation models is too gross to provide sufficiently accurate calculations for the precise information needs of Spain. One of the most frequent and conveniently detected errors in many hydrological studies in Spain involved evaluating reduced yields resulting from climate change carrying out calculation extended to basins (Ayala, F.J. and Iglesias, A. 2000) whereas calculations extended to sub-catchments or smaller units (Fernández Carrasco, P. 2002) tend to show a greater degree of reliability. This is true not only for studies of climate change, but also for most hydrological studies in Spain.

The temporal distribution of climatic parameters throughout the year, as was seen in point 1, completely conditions the generation of runoff. Heavy rainfall at very warm times of year does not generate yields which would be generated with lower rainfall during the winter months.

This is a particularly critical uncertainty, because it could have even more influence than the temperature increase value at annual scale.

It is also uncertain how the series will vary, not within the year, but at interannual scale. This information is unknown, and has not even been estimate, and only one attempt has been made to approach the subject, in the aforementioned article by Ayala, FJ. and Iglesias, A., which defined annual series that took as an average the average of the mean series deduced, and the standard deviation coincided with those of the present series. The mechanisms for generating series need to be improved in order to correct this uncertainty as much as possible.

- Uncertainties in the spatial distribution of rainfall and temperature.
Monthly distribution throughout the year of rainfall and temperature
Interannual distribution of rainfall and temperature (series)
Evaluation at the level of sub-catchments and small catchments

7.7.4. Soil behaviour and aquifer recharge

Uncertainties related to soil behaviour and the real factors conditioning recharge are very variable and range from uncertainties related to methods of calculation of potential evapotranspiration, leaf interception or the balance of water in the soil, to parameters that cause the useful part of rainwater recharging aquifers to be greater or lesser. Empirical methods have been validated for determined areas with given topographies and given climatic values, but the usefulness of these has not been validated in relation to different values inherent to climate change.

With regard to infiltration that is to become part of the aquifer recharge, it is known that this cannot take place while the soil does not present a surplus. That is to say, once the soil is saturated and continues to receive rainwater, surpluses appear, which constitute useful rainwater, part of which infiltrates to recharge the aquifer. The parameters that quantitatively define this division are unknown, but it is important to establish these, provided that if as,like seems, appears to level of hypothesis it depends on the time that the soil remains saturated every year and of the values of permeability of the subsoil, climate change might not affect groundwaters, or affect them intensely, in a positive or negative sense, depending on each case.

- Uncertainties related to the soil and aquifer recharge
Suitable methods for estimating possible evaporation and evapotranspiration
The specific phenomena of aquifer recharge
Calculations of useful rainwater under the new climate circumstances

7.7.5. Limitations of the simulation models

The models of numeric simulation and those based on empirical expressions have traditionally been used with good results, but some clarifications should be made. In theory, a model is as good as the data it is supplied with, but those that have been implemented or are being implemented undergo a process of fitting or calibration which gives them a particular validity with regard to use. Models for evaluating yields under specific circumstances of climate change, applied to determined scenarios, cannot be calibrated, because these series did not occur in reality and it is therefore impossible to what really took place with what has been calculated by a model.

Simulation models will have to be validated with the use of other current series which we will have to assume have been harmonised with others deriving from change. These are some of the basic limitations of the modelling process which needs to be developed and improved in order to partially eliminate these shortcomings and to make them reliable for the study of climate change.

7.8. DETECTING THE CHANGE

7.8.1. Continuous evaluation of hydric resources

The changes water resources are subjected to by climate foreseeable changes can be detected by means of the measurement and quantification systems being established in Spain. Changes in hydric resource are detected with the use of a plan for gauging river flows, the piezometry of groundwater, sample collection and analysis of surface waters and of groundwater catchment. All of this should be formalised by means of appropriate spatial distribution and frequency of sampling in order to make a follow-up of the evolution of the resources and of the quality thereof, with the necessary degree of reliability.

In Spain, there is a good metering network that could be improved, and which, in fact, is constantly being worked on. There is also a river-water quality network, and both of them can be used to implement a continuous follow-up in time and space of the evolution of surface yields, in quantity and quality.

There have also been reasonably complete networks for the control of aquifers, piezometry and quality, and a very precarious and deficient network for controlling yields from springs. The quality and frequency of the measurements taken by these networks has been declining, although plans currently exist aimed at improving these.

The disadvantage of data on flow measurement is that they do not reflect natural yields, but rather, they give values of surplus yields. The difference between these is basically the detractions made to satisfy water uses. This is why, together with the networks mentioned, another network is needed for measuring water uses, and this has bot yet been developed, and we recommend that it be carefully designed and implemented. These networks should also be complemented by networks for controlling extractions of groundwater.

7.8.2. Quantity and quality control systems. Surface and groundwater

The following is a synthesis of the control systems for the evaluation of water resources.

- Surface waters
Flow and yield metering networks
Flood control networks
Networks for the control of chemical and bacteriological quality in rivers
Quality control networks in lakes and reservoirs
Networks for controlling water uses and diversions

- Groundwater
Piezometric control networks in drilling and piezometers
General quality control networks
Specific quality control networks (salwater intrusion, nitrates, etc.)
Networks for water metering in springs and sources and differential water metering in rivers
Networks for controlling pumping in aquifers

These control systems are well established, or are being improved, in some cases, and in others, more generalised installation is recommended. With regard to the latter, it would be convenient to design, implement or clearly improve the control networks of surface and groundwater, along with the flow gauging networks in springs and sources.

7.9. IMPLICATIONS FOR POLICIES

Reduced hydric resources, as we have seen, affects a large number of sectors. Given that these sectors are regulated by means of specific policies, climate change affecting water resources will necessarily require the remodelled and redesigned policies.

- Science and technology policy
The science and technology policy will necessarily become involved, as a result of reduced water resources, an increase in investment and changes in priorization of criteria, and new research will have to be budgeted for, which could involve both resource generation methods (desalinisation) and methods for combating pollution, water purification and use optimisation.

- Water policy
Climate change, which will affect water availability, will lead to debates in the future on water policy, which will surely be more heated and in-depth than at present. Few policies will be so affected in such a continuous way.

One of the methods for correcting the impacts of climate change on water resources basically consists of using an improved and better-adapted water resources system and managing this according to a series of realistic rules related to the binomial resources-demand.

Water policy will be seriously influenced by variations in resources. The elements of regulation, supply, transport, distribution and quality protection of water resources, the interdependence of these, along with management regulations, will need to be adapted to political directives which should give priority to uses and establish stronger compromised related to interregional solidarity.

- *Energy policy*
This is another policy hat will be clearly influenced by a decrease in resources. It will be affected in three fundamental aspects – reduced energy production based on the use of water, obviously affected by shortened resources, an increase in energy consumption resulting from desalinisation operations and pumping in water transfers and from groundwater aimed at mitigating the new hydric deficits.

Resources will be reduced even more by changes in the temporal distribution of liberation of water of the reservoirs aimed at dealing with other uses, which are given more priority than hydroelectric energy, mainly agricultural ones. All of this should be considered and included in successive water policies.

- *Agricultural policy.*
Agricultural policy will have to be redefined as a result of scarcity of available water resources for irrigation. Irrigation methods aimed at water saving will be promoted, along with crops that require less water. More relaxed irrigation guarantees may be accepted, and on some occasions, irrigation may have to give way to more priority uses, such as human supply or livestock farming. Agriculture policy will have to give more consideration to the reuse of waters, mainly of urban origin.

- *Environmental policy*
Water has a double implication in environmental policy. On one hand, it is a transmitter, *par excellence,* of pollutants to the geosphere, and on the other, a priority element pollutant dilution.

In conditions of reduced ecological flows, environmental policy will have to spills and pollution levels.

- *Land planning*
The planning of water and land uses will have to consider a possible decrease in water resources resulting from climate change.

Land planning will have to adjust to definitions of land uses based more on the real possibilities of resources. In certain cases, we could even expect changes from high-consumption land uses to other, more efficient ones.

7.10. MAIN RESEARCH NEEDS

7.10.1. Analysis and enumeration of the parameters involved

Runoff generation and the subsequent generation of water resources, are affect by a large number of factors, which make evaluation of the impact of climate change therein very complicated. The following are the parameters considered to be most significant, although, as has already been seen, not all of them have the same degree of influence.

- Reduced rainfall
- Temperature increase
- Distribution of rainfall and temperature in discrete spaces (with spatial sufficiently low discretisation).
- Temporal distribution throughout the year of rainfall and temperature.
- Type of treatment given to these data and how the series intervening in calculations are generated.
- EV values and the variability of these, with climatic and topographic parameters.
- PET values and the variability of these, with climatic and topographic parameters and latitude.
- Canopy interception
- Soil retention
- Water reserve for plants
- Surplus management
- Infiltration of groundwater
- Surface and groundwater resources system
- Regulations for system management
- Irrigation methods
- Water uses

The parameters of incidence are divided into three main groups; those depending on climate change and the spatial and temporal distribution thereof, which is the mystery *par excellence*, and the way these are to be treated, those relating to the generation of runoff itself, where soil processes come into play, and lastly, the parameters of incidence deriving from the system of available water resources and the way this is managed.

7.10.2. Quantitative evaluation of confidence levels

Quantitative evaluation of the reliability of the data and processes related to the generation of water resources, all of which revolves around foreseeable climate change, is a task that lies within the realms of hypothesis, and not based on validated facts, as required by science. We can therefore assume that the only levels of reliability are based on ideas that will vary in time and, above all, depending on how analysis is focussed.

In relation to currently available databases needed to calculated predicted decreases in water resources, rainfall and temperatures and the spatial distribution of these, the confidence level can be considered **Low (**)**. The databases present very low high variations in medium and long-term estimates, which requires the use of scenarios which differ greatly and which overdiversify the results of runoff predictions.

The second group of parameters of incidence, refers to the available knowledge of the process of runoff generation and whether this knowledge has been suitable adjusted for application to big variations in climatic parameters. It should be pointed out that this process has had a **High** (****) confidence level, but this was due to the possibility to contrast the empirical methods with the integration of the hydrograph obtained from real measurements in rivers. The unavailability of effective contrasts of resources, estimated with the use of methods based on the role of water in the soil, reduces, to say the least, the confidence level, and the level thereof, in the parameters of incidence included with the group constituted by the runoff generation process, is therefore considered to be **Medium (***)**. Within this group, there are aspects with a higher confidence level compared with certain others, but this classification extends to the whole group as an average.

Finally, the confidence level existing in the water resources system and the way this is managed should be considered **High (****)**. In this groups of incidence, what is assessed is the degree of reliability in the calculation of water resources based on pre-established runoff rates and on an existing water resources system or one that can be designed included in the management regulations. There is a significantly high degree of knowledge and a great deal of experience in this respect in Spain, with regard to both the development of systems and to the use of numerical management models aimed at supporting the adoption of regulations for the use of these systems.

7.10.3. Definition of research needs

There are many needs for research, as surely occurs in all the sectors influenced by climate change, but if we follow an established order in the parameters of incidence, we can consider the following ones to be important:

Research aimed at improving and consolidating the estimates of predictable rainfall and temperature values, with the appropriate spatial and temporal distribution of these for the different horizons of this century.

Research aimed at defining methods for the generation of series of climatic data based on the scenarios considered.

Research for the evaluation of evaporation and evapotranspiration, according to topography, latitude and climatic parameters distributed in time and space.

Research into the role of water in the soil, interception, water reserve for plants, etc., in order to improve the empirical methods for calculating useful rainwater.

Research aimed at establishing more reliable knowledge of phenomena of aquifer recharge from the soil, which at present are only estimated through the decomposition of the recession curve of the hydrograph.

Research for the development of a standard numerical model or for the analysis and adaptation of existing ones, in order to computerise the calculation of surface and groundwater yields, and for use as a model for comparing the different hypotheses of successive studies. (The designed or selected model should include all the parameters of incidence and the representative physical indices of the catchment.

Lastly, we ought to continue researching and designing methods and models for backing decisions related to the design of water resource systems and the way these are managed.

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8. IMPACTS ON SOIL RESOURCES

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ABSTRACT

Large areas of Spain are currently threatened by desertification processes, in particular by the impact of forest fires and by the loss of fertility of irrigated land due to salinisation and erosion. The climate changes projected would exacerbate these problems in a generalised manner, especially in the dry and semiarid regions of Mediterranean Spain.

One of the essential components of the natural fertility of soils is their organic carbon content. It is estimated that the variations in these contents range from less than 4 kg C. m^{-2} in areas such as the Ebro valley or the southern Mediterranean coast, to over 20 Kg C. m^{-2} in the mountain areas in the North or Northwest, and can even reach 30 Kg C. m^{-2} in some forest soils in Galicia, and it can therefore be said that in Spain, practically the same variation ranges are found with regard to the accumulation of organic carbon as in the rest of the world. A mean value of organic carbon loss of 6-7% is estimated for each degree of temperature increase, and this value can increase or decrease according to the change in rainfall and also according to the characteristics of the soil itself and the uses thereof. The carbon cycle models and studies of climate transects suggest a generalised decrease in soil organic carbon as a consequence of the temperature increase and of the drought projected by the climate change models, which would negatively affect the physical, chemical and biological properties of the soils and would increase the risk of erosion and desertification. The areas in which greater losses of organic carbon could be expected would be the more humid ones (N of Spain), as well as the land uses with higher organic carbon contents (meadows and forests).

Changes in land uses and management provide good possibilities for counteracting the predicted negative effects. Among these are the reforestation of marginal and barren land, and an agriculture system which, through the appropriate management of farming techniques, tilling, irrigation and management of organic amendments, increases the organic carbon content of the soils and their fertility, triggering a multiplying effect of the ecosystems' capacity to fixate atmospheric carbon.

The European Strategy for Soil Conservation, the Common Agricultural Policy, with its agro-environmental measures, the Spanish Forestry Plan and land use planning at different scales of management constitute tools for the conservation of edaphic resources and the mitigation of the impacts of climate change on the soil and the associated ecosystems.

A basic research need in relation to edaphic resources involves an inventory thereof at a scale useful for management (at least 1:50.000), with which to evaluate the state of the resources, to plan management and to project change tendencies. In Spain, abundant local data are available that deal with the characterisation of soils, and these offer interesting possibilities for scientific use. These data, which are varied and heterogeneous with regard to structure, should be compiled and homogenised, universal databases being used as a reference, such as that of FAO-CSIC (Spanish higher scientific research centre). Finally, long-term soil studies in experimental stations, representative of the main land/soil types and uses, within the existing RESEL network of permanent experimental stations (Biodiversity Conservation Dept.), constitutes a reference of great value for the detection of changes in soil properties.

8.1. INTRODUCTION

Soils are the support of primary production in terrestrial ecosystems. Therefore, agricultural production of food and fiber for the human population is strongly dependent on soil resources. At the ecological and human time scales, soil resources are non-renewable. Therefore, soil conservation is a critical factor to ensure increasing food demands.

Soils can be a carbon (C) source and sink. Therefore soils contribute to the regulation of the carbon cycle and its comsequent effects on climate change. Changes in land use constitute the driving force that determines the soil's role as a source or as a sink of C. Tilling of land has led to a loss of organic carbon (which we will refer to hereinafter as OC) and an immediate increase in carbon emissions, whereas the reforestation of croplands causes an increase in carbon sequestration. However, sequestration of C under forestry or other non-agricultural land uses often only slowly replaces OC lost through cropping, and such differences in time scale between loss or change of soil properties due to man and their reversal are commonly several orders of magnitude different. Furthermore, the properties of soils are sensitive to climate change. The predictions by global circulation models for the Mediterranean basin, which would aggravate drought, would increase the risk of intensification of desertification processes.

Many of the impacts of climate change on soils are influenced by soil OC. In mineral soils, the approximate relationship between organic matter and soil organic C is 1.724 x % OC = % organic matter. Temperature increase would cause a higher decomposition rate of the OC. Increased drought would have the opposite effect. The possible increase in plant productivity due to the fertilising effect of an increase in atmospheric CO_2 would lead to an increase of OC inputs to the soil, especially with intensive cropping (assumig no hydrological or nutritional limitations). In natural ecosystems where productivy is limited by N shortage, increased atmospheric N deposition would increase OC inputs to the soil. On the contrary, decreased productivity due to intensification of water stress leads to losses of soil OC. The foreseeable increase in the occurrence of forest fires (see chapter 12) would cause losses of OC (especially of litter) and would increase the risk of erosion. Increased soil erosion causes the loss of upper soil horizons richer in OC. In areas in which forest fires are a recurring phenomenon, like in the Mediterranean basin, the production of highly stable forms of OC during combustion of biomass (charcoal) can contribute to the stabilisation of C in the medium term. All these processes do not exclude each other and some of the feedbacks may be positive, causing a multiplying effect.

OC is intimately linked with the natural fertility and productivity of soils: 1) as a source of macronutrients, especially N and P; 2) in relation to the substrate of the soil's microbial activity; 3) humified carbon contributes greatly to the capacity to retain nutrients and pollutants (capacity for cationic and anionic exchange capacity); 4) humic substances of lower molecular weight (fulvic acids) improve the solubility of some essential micronutrients, and of toxic metals; 5) it is a critical factor in the development and maintenance of soil structure and in the stability of soil aggregates and, consequently, of the physical properties that depend on these factors: water infiltration capacity, water holding capacity for plants, aeration, compaction, erodibility.

Another process that would probably be affected by climate change is soil salinisation. Projected Increasing in evapotranspiration and drought would raise water table, saline intrusion and accumulation of salts in the rooting soil depth in arid and semiarid lands.

In summary, the processes that would most influence the loss of fertility in Spanish soils, leading to their degradation, are: loss of OC content, decreased structural stability, reduced soil biological activity, increased risk of erosion and the spread of salinisation. These processes can be reduced with the application of appropriate farming techniques, tilling, irrigation control and management of organic amendments, along with the reforestation of barren lands. In short, those measures promoting soil fertility would set off a multiplying effect in the ecosystems' capacity to fix atmospheric carbon in the long-term. Of course, land use will almost certainly change as a consequence of climate change, opening opportunities to novel crops and varieties adpated to the new conditions, including the corresponding changes in cropping systems.

8.2. SENSITIVITY TO THE PRESENT CLIMATE

8.2.1. General characteristics of Spanish soils

According to the cartography of Spain's soils by IGN (National Geographic Institute of Spain) (1992, table 8.1, Fig. 8.1):

- Around 17 % of the area corresponds to little developed, shallow soils (many of the Entisols), generally on slopes, plateaus, and mountain areas,
- 1.6 % of valley soils, fertile in the broad sense, on river terraces (Fluvents, included in the order Entisols)
- a total of 60% are little differentiated soils, but modeately deep (Inceptisols) and of medium fertility,
- 9% of soils under arid climates (Aridisols), including soils with accumulation of calcium carbonate, gypsum, and/or soluble salts.
- 9 % of soils with subsurface accumulation of clay (Alfisols), fertile, of which one third are typically Mediterranean red soils.
- soils rich in OC, very fertile, of the Mollisol type, only constitute 0.2 % of Spain's territory.
- 1,6 % of very clayey soils, which crack when they are dry (Vertisols) mostly used for agriculture. The Vertisols are particularly distributed throughout Andalucia and Extremadura regions.
- Well-developed acidic soils (Ultisols and Spodosols) only occupy 0.4 % of the territory, mostly in northern Spain.
- Finally, organic soils (Histosol), with a large content of organic carbon, which are trivial in extent in Spain (0.04 %) although they are of great ecological and scientific value.

Table 8.1. *List of soil types (USDA 1987) in Spain. Source: IGN (National Geographic Institute of Spain) 1992 (de la Rosa 2001)*

Order	Units	Percentage, %	Area, ha
Alfisols	368	8,86	4507160,2
Aridisols	411	9,19	4672759,6
Entisols	830	18,90	9613443,7
Histosols	4	0,04	20813,2
Inceptisols	1612	60,73	30891369,6
Mollisols	2	0,21	104746,5
Spodosols	62	0,22	112146,8
Ultisols	5	0,24	121689,9
Vertisols	51	1,62	826275,5
TOTAL	**3347**	**100**	**50870405,1**

SEIS.net (Spanish System of Soil Information though the Internet (de la Rosa 2001, http//:www.microleis.com) shows in an easy-to-use format the information available on the current state of quality and degradation of soils in Spain, including a Digital atlas of Soil Regions and an on-line Soil Database.

Fig. 8.1. *Map of soil sub-orders in Spain, according to Soil Taxonomy, USDA 1987); IGN* 1*992/SEISnet. (de la Rosa 2001)*

8.2.2. Soil processes particularly sensitive to climate change

By sensitivity of soils to climate change (CC), we understand the intensity and extent of the response generated in the soil properties and processes as a consequence of a modification in the parameters of the climate.

Soil properties that could be modified by CC would be OC content, characteristics of soil biota, moisture and temperature regimes and processes such as erosion, salinisation or physical, chemical or biological fertility. The climatic parameters driving these changes would be temperature, rainfall (quantity, intensity and temporal distribution), together with atmospheric chemistry, especially carbon dioxide and nitrogen and sulphur compounds.

Many of the soil properties are quite resistant in relation to short-term variations in climate, with effects that are difficult to detect due to the great impact of land use and land use changes, especially if we consider the great spatial variability of soils. It is therefore impossible, with the knowledge currently available, to determine the sensitivity of Spanish soils to presently perceived climate changes in an accurate and quantitative manner, but some examples can be given in which these relationships between climate and soil are evident.

a) <u>OC Mineralisation.</u> Taking into account that this process depends, in the first place, on the soil climate, we could presume that, within certain thresholds, the highest the temperature and the highest the number of days with soil moisture greater than wilting point, OC mineralisation will be more intense. Therefore, the coincidence of a thermic soil temperature regime with an udic or even an ustic soil moisture regime (Fig. 8.2) would define those regions in which the sensitivity of Spanish soils to the degradation of and potential for absolute loss of organic matter is greater. It should be emphasised that change in the nature of organic matter, i.e. its composition, can be as important as the change in the amount of OC in the soil.

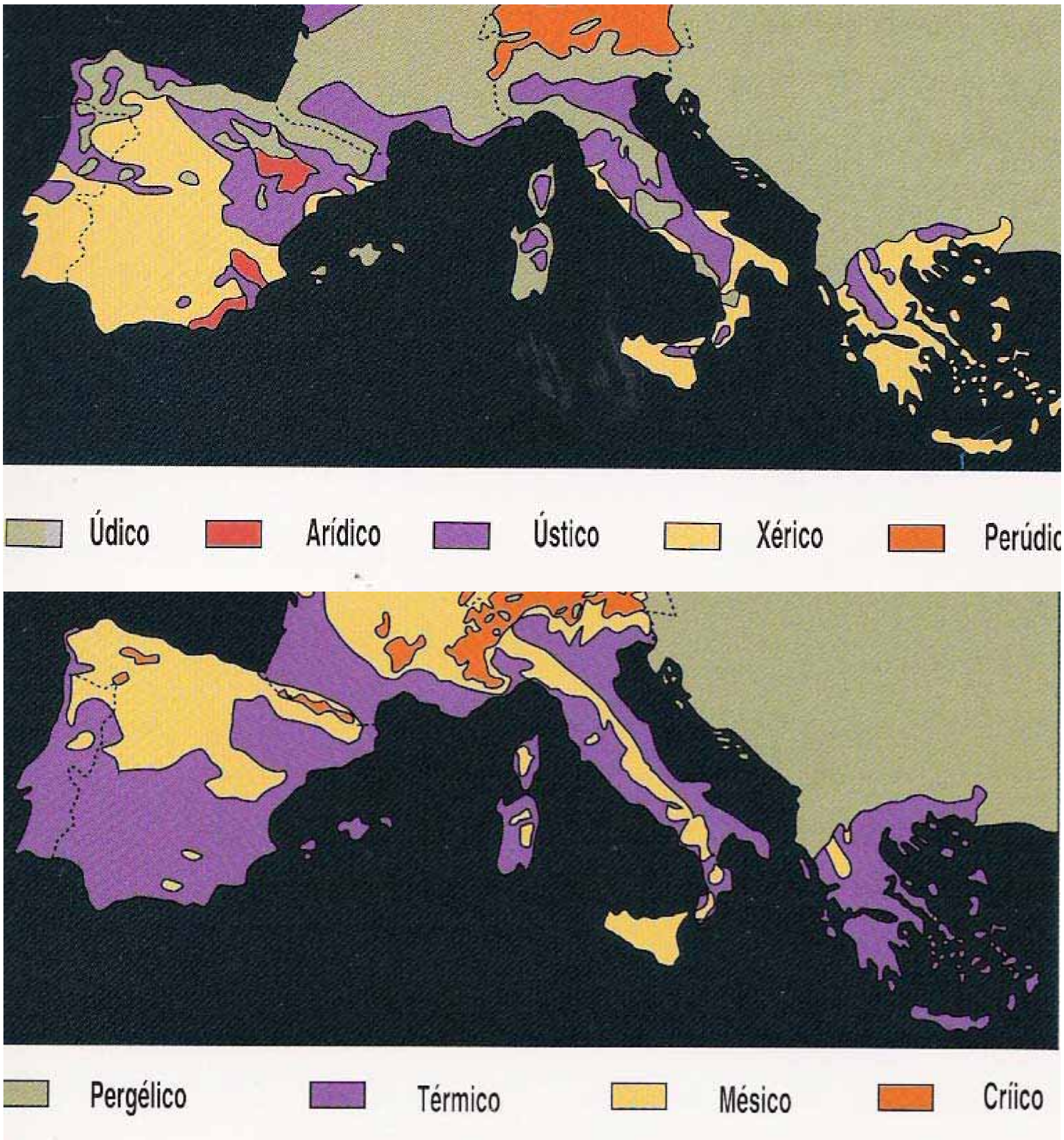


Fig. 8.2. *Soil moisture (above) and temperature regimes (below) according to the Soil Taxonomy criteria for southern Europe. Adapted from the Soil Map of European Communities 1:1.000.000 (CEC 1985).*

b) Physical status of the soil. If we accept, as most authors usually do, that 2.3% soil OC defines a threshold, below which there is a significant acceleration of the processes of physical degradation, then we can consider that those soils with values lower than the aforementioned threshold (in the map of Fig. 8.7, those presenting less than 12 Kg C m^{-2}) will be the ones most sensitive to the physical degradation of the soil, and even to loss of soil fertility through the effects of physical soil properties on biological and chemical processes. However, that threshold is only a very rough indicator that should be considered with care in assessing specific soil conditions.

c) Soil erosion. According to the Universal Soil Loss Equation, widely used for predicting hydric soil erosion, factor k is the parameter that defines the sensitivity of the soil to soil erosion.

Factor k depends on soil OC, texture and structure, the former and the latter being sensitive to climate change (see previous paragraph). In addition, wind erosion is likely to increase as strominess do so and plant cover is reduced.

d) Salinisation. The increasing aridity of the climate, combined with irrigation of poorly drained soils with waters that could be of deteriorating quality, constitutes a risk of salinisation of the soil and, eventually, of runoff waters.

8.2.3. Land use

In the short term, changes in land use result mainly from cultural, political and socioeconomic factors, more than from the direct impact of climate. The effects of land use changes on the soil can be as great, if not more, than those of climate change itself (Vitousek 1992). In the last half century, the territory of Spain, like that of much of Europe, has been subjected to big changes, which continue to be seen and to interact in a complex fashion with the effects of climate change on soils.

C stocks in soils and vegetation have increased during the XXth century in Spain due to the abandonment of marginal croplands, particularly since the 60s and promoted in the last decade by the EC's Common Agricultural Policy, together with the extensive reforestation carried out (over 3 Mha, ICONA 1989). The large forest fires that started to occur since the 70s must have partially counteracted this carbon accumulation. Wildfires tend to consume part of the understorey, some of the thin branches and the litter (around 65% of the C contained in all these fractions in an experimental high-intensity fire; Serrasolses and Vallejo 1999).

According to data from the European Environment Agency, Spain, after France, is one of the European countries that lost most agricultural land during the 90s (1.8% of the territory). A large part of this territory has been used for housing (0.3%) whereas the rest (1.5%) has become forest (basically through natural regeneration and plantations). The reduction of croplands for housing is especially concentrated along the coast and close to the big cities. In this case, the problem of soil sealing arises, which causes the physical destruction of the soils or profoundly modifies their physical, chemical and biological properties. Furthermore, sealing can cause hydrological problems, local temperature increases, changes in groundwater levels, greater mobility of pollutants and overloading of water courses, particularly during torrential rains. Where polluted waters enter river estuary systems and the coastal zone, degradation of this environment can occur and is related directly to soil problems.

The four economic scenarios by the IPCC involve predictions of changes in land use from 1990 to 2050. Briefly, they can be summarised for those impacts in land use as follows:

- A1 (rapid economic growth): slight decrease in croplands, increased pastures. Decrease in forests and other uses. This scenario involves the maintenance of previous tendencies in changes in land uses, governed by economic forces.
- A2 (local identities): no changes in land uses have explicitly been developed in this scenario.
- B1 (services and information economy): slighter decrease than in scenario A1 of the area with crops, decrease in pastures and increase in forests and other uses.
- B2 (local economies, sustainability): large increase in crops and pastures, decrease in forests and a sharp decrease in other uses.

These scenarios do not discriminate the location of the change, which will evidently vary geographically. In Europe (and Spain), economic scenarios A1 and B1 would lead, in the medium term, to the continuity of the gradual abandonment of marginal agricultural lands. Probably, in spite of assumptions A1 and B2, there would be an increase in the area occupied by forests expanding in old fields. Options are therefore provided for the appropriate management of marginal abandoned lands and forest restoration.

8.2.4. Desertification

Spain is one of the countries affected by desertification (United Nations Convention on Desertification, Annex IV), exacerbated by human activity under arid conditions (Fig. 8.3). The basins affected are defined using estimates of soil erosion, occurrence of forest fires, the degree of exploitation of hydrological resources and drought intensity (see draft of the National Action Programme against Desertification, PAND, by the MMA – Ministry of Environment). Two fundamental components of desertification in Spain are soil erosion (Fig 8.4) and the salinisation of the soil. At present, it has been recognised that 32.5% of Spain's surface area is seriously affected by desertification (PAND, MMA). According to the same sources, 42% of the country's area is above tolerable erosion limits and mainly involves the Guadalquivir, Ebro, Tajo and Southern basins (Fig. 8.4). In Spain, in 1991, it was estimated that the direct costs of erosion reached 280 million € and the cost of recovery measures would require 3,000 million € over a period of 15-20 years. Water erosion in Mediterranean conditions is highly episodic at present. For example, in a complex of catchments in dry Mediterranean climate conditions in Valencia, only 3 to 4 sedimentary events are recorded per decade, with erosion producing rainfall thresholds between 30 and 60 mm day^{-1} (S. Bautista, personal communication, European project SPREAD). The predicted changes in relation to an increase in extreme climatic events that may affect Spain (Millan *et al*. 2004, in press) would lead to an exacerbation of the risk of soil erosion.

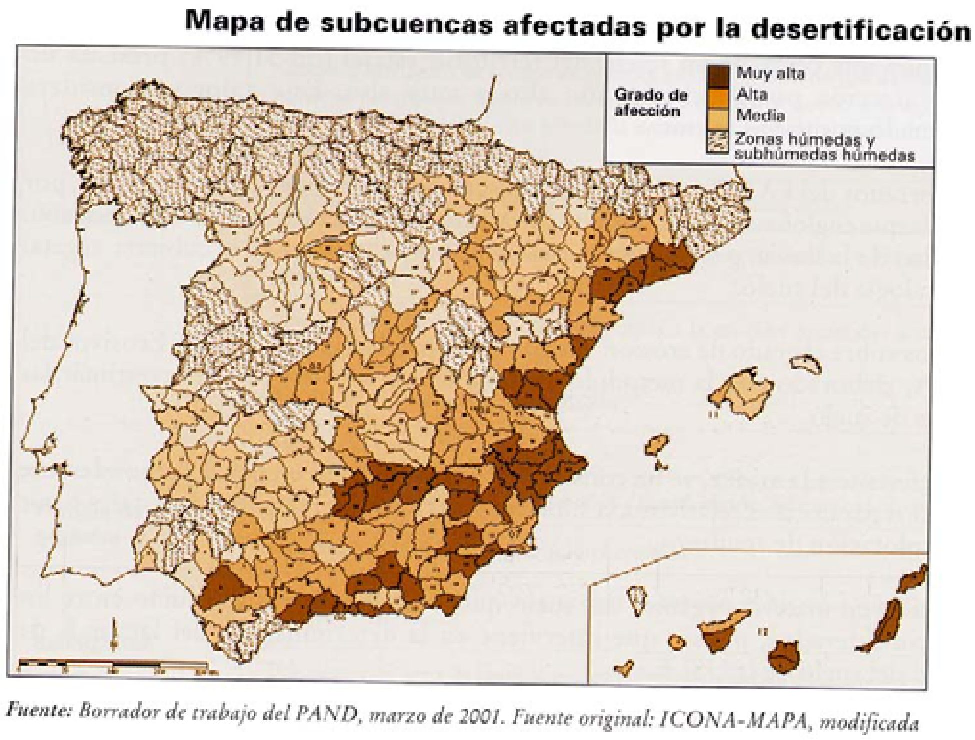
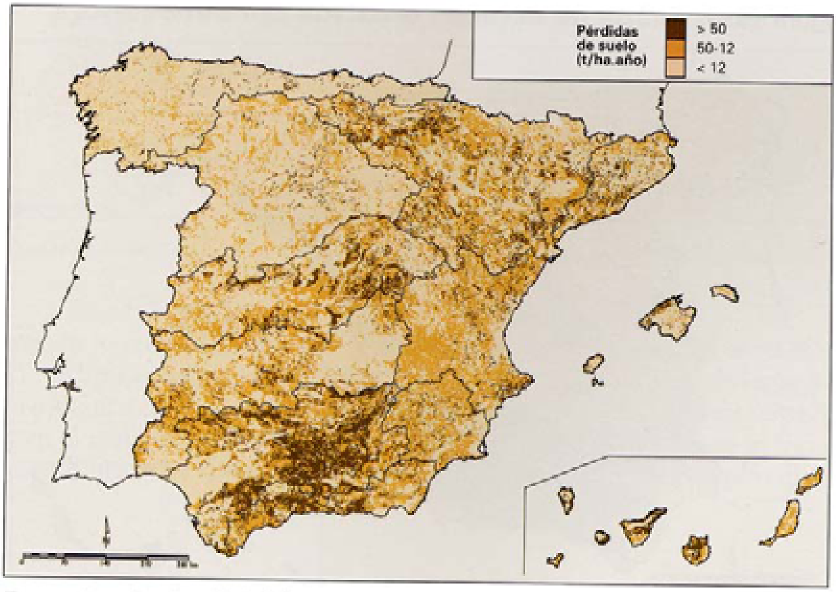


Fig. 8.3. *Map of sub-watersheds affected by desertification in Spain.*

Mapa de estados erosivos



Fuente: *Borrador de trabajo del PAND, marzo de 2001. Fuente original: ICONA-MAPA, modificada*

Fig. 8.4 *Map of erosion condition in Spain with estimates of soil loss.*

According to the soil map of Spain, by the IGN 1992 (Fig. 8.1), saline soils (*Salorthids*) occupy around 180,000 ha, 0.35% of the country's surface area. In the EU, salinistion of the soil affects 1 million hectares, mainly in the Mediterranean countries (C.E. 2002). The problem of soil salinisation seriously affects 3% of the 35,000 km^2 of irrigated land in Spain, and 15 % is at great risk, especially in the Guadalquivir, Ebro, Guadiana, Tajo and Southern basins and along the East coast (PAND, MMA).

8.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

8.3.1. Impacts on the evolution of the soil

The relationship between soil types and temperature, rainfall and evapotranspiration is well known. Only certain properties can be altered, however, over short periods of time, by changes in climatic factors, like, for example, content of soluble salts. In this way, soils affected by salinisation may change their distribution (Salorthids, Soil Taxonomy, de la Fig. 8.1).

Due to possible changes in temperature, more notable in areas of greater latitude, there could be a great and very rapid loss of organic matter in peaty soils (*Histosols* in Table 8.1 and Fig. 8.1). However, the global impact of these losses would be low owing to the small surface area occupied by peat soils in Spain.

8.3.2. Salinisation: in relation to climate change and intensification of agriculture

Salinisation of soils is probably the most important degradation process affecting the production of fibre and foodstuffs in countries with arid and semiarid climates. The most common cause of salinisation is associated with irrigation in areas with poor drainage, with fine-textured soils, with the use of water containing an excessive amount of salts for irrigation, and with marine intrusion. New irrigation programmes in sensitive areas, the intensification of agriculture and the overexploitation of aquifers are the main culprits of salinisation in Spain. The National Irrigation

Programme (Dirección General de Desarrollo Rural 2001) plans for the extension of the irrigation system in Spain up to 2008.

The problem of salinity is associated with the presence of salts more soluble than gypsum in the soil, generally NaCl and Na_2SO_4 (sulphates are more abundant in inland areas). When the water balance of the soil does not produce water surplusses which remove salts from the soil by natural drainage or the soil is not appropriately drained, causing water logging, the salts tend to accumulate on the top soil, osmotically affecting water absorption by the plant (physiological drought) and producing toxicity. Irrigation of soils with a high salt content can aggravate the problem if there is not appropriate drainage because salts are brought to the surface by capillary action and by the increased growth of the irrigated crop. This accumulation of salts is therefore characteristic of climates with a low Rainfall/Potential Evapotranspiration ratio. As the projections of climate change for Spain forecast a decrease in this ratio, the salinisaiton problems can be expected to worsen. Likewise, a possible rise in sea level would exacerbate the problems of marine intrusion in the phreatic layers, along with those related to the spread of salinisation to coastal areas and the possibility that tidal influence of saline waters will extend further inland along rivers and estuaries.

The intensification of agriculture in the large watersheds and in the coastal areas of East and Southeast Spain, accompanied by increasing aridity of the climate, will cause the problem of salinisation to spread (Fig.8.5), with serious consequences related to the reduction of harvests and/or the need for extra investments for mitigating this problem.

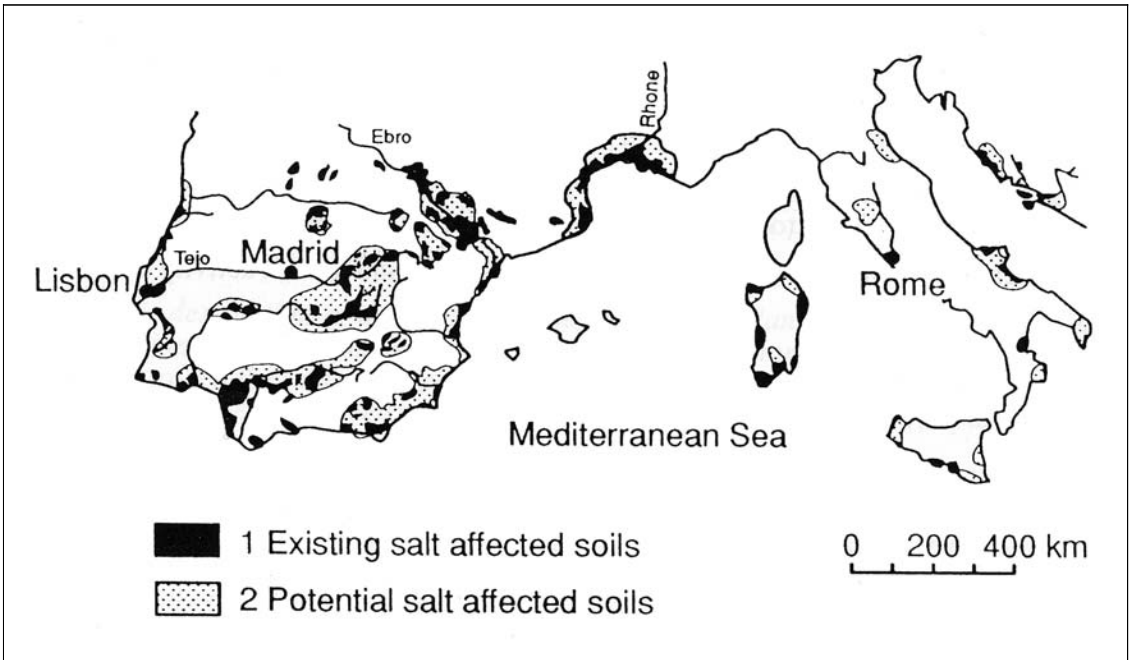


Fig. 8.5. *Distribution of salt affected soils and the potential spread of these as a consequence of climate change (Pérez-Trejo 1992).*

Reclamation of cultivated saline soils is difficult and costly. The techniques are based on leaching out the salts, using drainage and large amounts of non-saline water, together with crops that are tolerant to salinity and farming techniques that minimise the accumulation of salts in the rooting soil depth (for instance mulching). In any case, the reclamation of soil salinity always transfers the problem (the salts) downstream, to the river or to the neighbouring lands at lower elevations (Vallejo 1999) with the possibility of greater salinisation of lands bordering estuaries and further problems in the coastal zone.

In some cases, natural saline soils have been subjected to recovery projects for agricultural use. One example of this is the Guadalquivir marshes, where an area of 50,000 ha was recovered with the installation of a drainage and irrigation system (Grande Covián 1967) and which is currently used for cotton and sugar beet crops with good results. In this area, Moreno *et al*. (1995) studied the dynamics of salts and water, the results showing the good functioning of the drainage system and the salt leaching during cultivation with irrigation.

8.3.3. OC Balance

In a Mediterranean context, in which the soils tend to have a low organic matter content, OC increase could favour the physical, chemical and biological properties of the degraded soils.

8.3.3.1. Impact of the soil on climate change

Apart from the impacts of climate change on the properties and functioning of the soil, it is also of great interest to learn of the influence of the soil on this change. The global amount of organic carbon in the soil has a direct influence on atmospheric CO_2 levels. Slight changes in OC, whether these be positive or negative, can have an appreciable effect on the content of atmospheric CO_2 levels. Furthermore, in permanent or temporal waterlogged soils, emissions of CH_4 (methane) and N_2O (nitrous oxide) also contribute to the greenhouse effect.

Sequestration of organic carbon by terrestrial ecosystems forms part of a very active biological cycle, and a large amount of the carbon currently retained by soils can return to the atmosphere in relatively short time. In this way, carbon sequestration by terrestrial ecosystems should be considered as temporary storage, rather than permanent. In this sense, it is estimated that the soils used for cropping have lost between 20 and 40% of their previous OC under natural vegetation, and it is believed that through the use of conservation tilling practices, the levels of soil OC can be partly recovered.

In terrestrial ecosystems, current carbon stocks are much greater in the soils than in the vegetation, particularly in non-forested ecosystems at medium and high latitudes. Besides, the return of stored carbon to the atmosphere is slower in the soil than in the vegetation. Carbon stored in the soil is also much better protected against fires and other disturbances.

8.3.3.2. Carbon content in Spanish soils

The organic carbon content of the soil is the result of the balance between the OC inputs and mineralisation, both of these depending on climatic conditions. According to the estimates by Tinker and Ineson (1990, reused by Bottner *et al*. 1995 to discuss Mediterranean soils, Figure 8.6), the distribution of the carbon content of soils throughout the world varies from less than 2 kg C m^{-2} for the soils of sub-desert areas, up to over 30 Kg C m^{-2} in the tundra and rain forest areas.

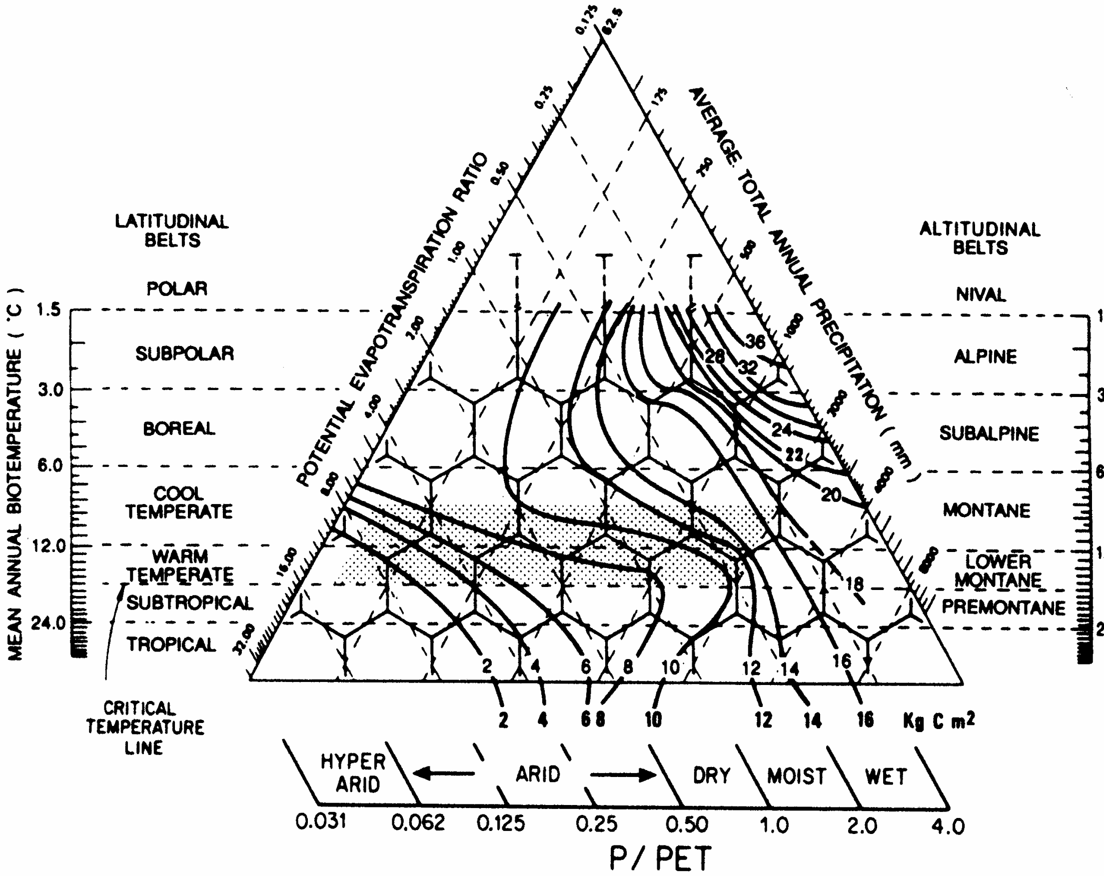


Fig. 8.6. Organic Carbon content (in Kg. m^{-2}) of the worlds' s soils. Bottner et al. 1995. The shaded area shows the range corresponding to Mediterranean soils.

For Spain, Rodriguez-Murillo (2001) used a set of 1,030 soil profiles to study the geographic distribution of their carbon content, and made a map (Figure 8.7) on which the estimated variations range from less than 4 kg C m^{-2} in areas like the Ebro valley or the southern Mediterranean coast, to over 20 Kg C m^{-2} in the mountainous areas of the North or Northwest. In the same sense, for agricultural soils, accumulations of organic carbon are higher in Spanish, Atlantic climate soils than in those existing in the Mediterranean climate (Fig. 8.8). Barral and Díaz-Fierros (1999) showed that the forest soils of Galicia could reach 30 Kg C m^{-2}, which demonstrated that Spain presents practically the same variation ranges of OC accumulation as the soils at world scale.

The second most important factor regulating OC content is the type of land use, along with the type of management the land is subjected to (Table 8.2, Fig. 8.9). The same study by Rodriguez-Murillo (2001) presents a table showing the main land uses with their carbon content, where it can be seen that it is shrubland uses that have the highest proportion, with an average content of 11.3 Kg C m^{-2}, followed by deciduous forest, with values of 9.36, whereas dry farming crops, with 5.08 Kg.C m^{-2} are the ones that present the lowest amount. The cropping systems that include organic amendments such as compost, fallow, burying crop residues, etc., always maintain a higher OC content in the soil than those that do not or that are subjected to burning of stubble, which accelerate mineralisation.

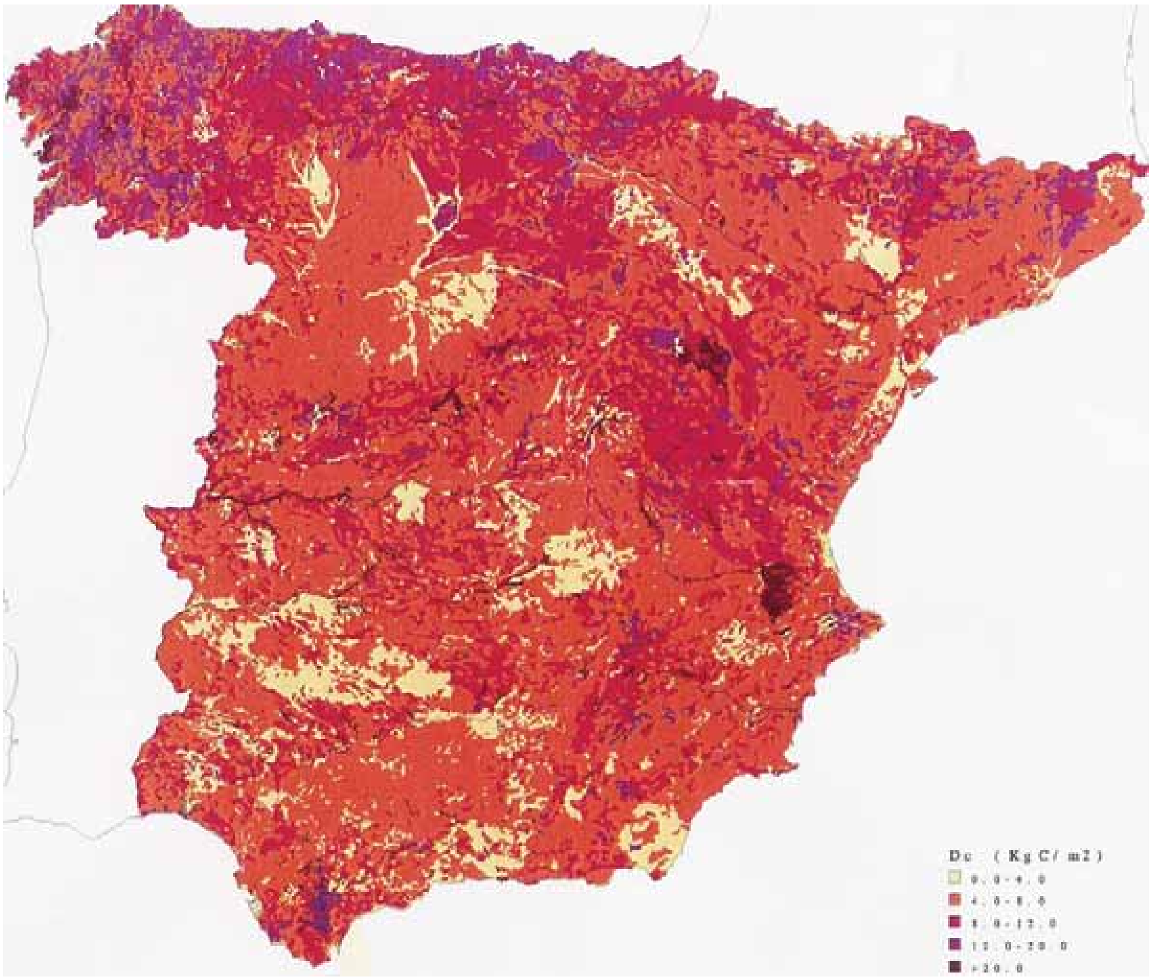


Fig.8.7. *Content of organic carbon (up to 1 m deep) in Spanish soils (Rodriguez-Murillo 2001).*

Table 8.2. *Total carbon under the main land uses on the Spanish Peninsula. According to Rodríguez-Murillo (2001).*

Land use		Area Km^2	Carbon kg m^{-2}	Total carbon Tg
Forests	Conifers	63 010	7.50	473
	Broadleaved species	23 991	9.36	225
	Mixed	18 934	12.1	229
	Total	105 935	8.74	926
Shrubland		78 492	11.3	890
Shrubland + trees		40 938	8.20	336
Dry farming crops		121 740	5.08	618
Others		147 458	6.28	926

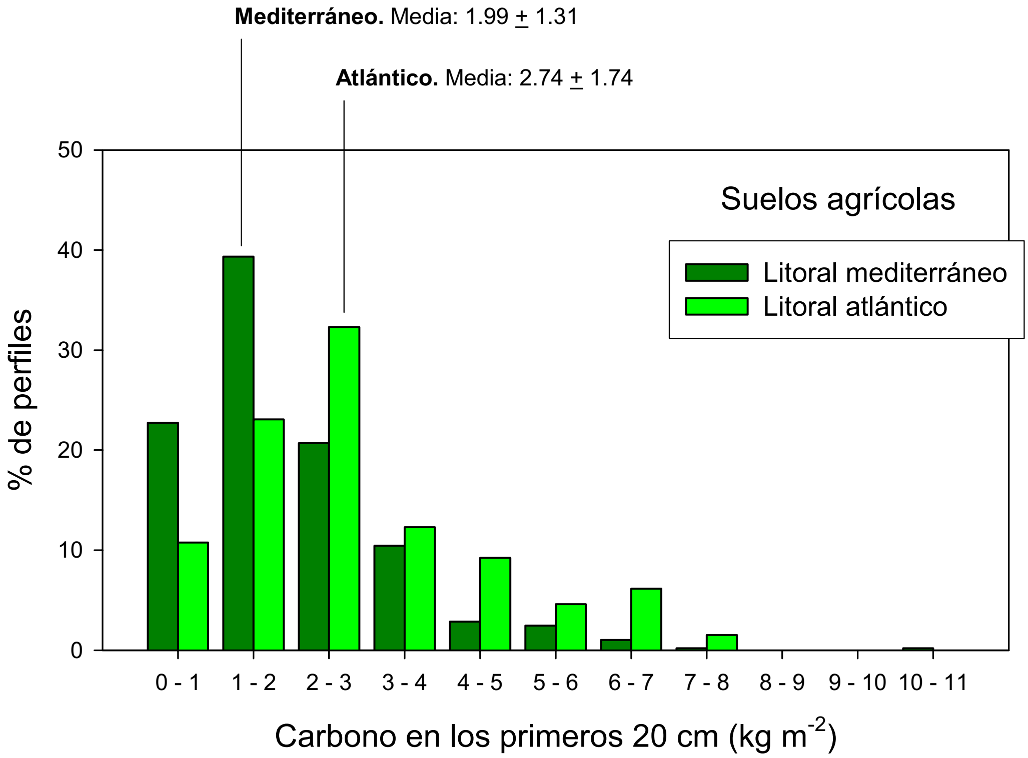


Fig 8.8. *Accumulation of carbon in the arable layer of Spanish soils of Mediterranean and Atlantic climate. Source: Rovira* and *Vallejo (personal communication), Evaluation of C in the soils of the Mediterranean area, OECC.*

8.3.3.3. Effect of climate change on soil OC in Spain

Climate change will have an influence on the OC content in the soil by means of a direct effect on the accumulation and mineralisation processes, and indirectly through the influence on changes in land use. According to different studies based on models, the indirect influence of changes in land use will probably be more important than the direct impacts on the processes regulating the OC balance of the soil (Parshotam *et al.* 2001). It is impossible to make accurate predictions of the response of ecosystems to these changes. There are big knowledge gaps, because most papers published simulated experimentally an increase in atmospheric CO_2, or a temperature increase (with or without decreased rainfall), but not both effects at the same time. Two groups of effects, however, can be mentioned:

A) Effects of an increase in atmospheric CO_2

Possible increase in primary production. If we accept the idea of increased primary production derived from the fertilizer effect of elevated atmospheric CO_2, the maintenance of sequestrered carbon in the soil would be relevant if the excess of fixed carbon is allocated to slow-decomposing forms (structural carbon: lignocellulose, suberin, various resistant forms). The information available seems to suggest the opposite. In meadow ecosystems in the USA, in a Mediterranean climate, Hungate *et al*. (1997) observed over three years an increase in biomass, roots, buried detritus and soil OC. The increase in soil OC, however, appears to be concentrated in labile fractions, the medium-term stabilisation of which is unclear: it could be lost as easily as it is accumulated. More important than the increase itself is the acceleration of the carbon cycle in the soil. The authors are skeptical with regard to the capacity of these meadows to accumulate more carbon. The combination of the increase in CO_2 and in temperature would result in a decrease in primary production in the medium-terrm (see chapter 9 and section B below).

Decreased quality of the OC. Specifically, there is an increase in the C/N index. It is considered to be a probable result of the increase in atmospheric CO_2, which initially should lead to a slower decomposition of plant residues, and therefore to greater accumulation of carbon in the soil. It is unclear whether this really occurs, because the experimental studies have not detected, in a conclusive manner, that the plant residues in CO_2 enriched atmosphere decompose more slowly than the control plants. De Angelis *et al*. (2000) observed a decrease in the decomposition rate of three Mediterranean species, but the decrease observed is minute and would be undetectable in real conditions. Particularly important is the observation by Coûteaux *et al*. (1991), in the sense that the outcome of CO_2-enriched atmosphere depends on the richness of the animal community of the soil and on the complexity of its trophic web: in soils with a poor community and a simple trophic web, the litter obtained under CO2-enriched atmosphere decomposes more slowly than the control litter, but this result is reversed when the soil contains a varied community and a complex trophic web.

Effects on microbial activity. Positive effects have been observed on microbial activities and on various enzimatic activities (Moscatelli *et al*. 2001), which in theory would lead to greater decomposition activity and therefore to a decrease in the organic carbon content of the soil. The effects, however, appear to be short term; in very few years, normal activity values are regained. This result should be considered with care, because it is practically impossible to separate the direct effects on microbial activities from the indirect effects of inputs of root exudates and other labile forms of carbon from the roots, which also undergo an increase due to the CO_2 increase (which does not last more than a few years, either).

B) Effects of temperature increase

Primary production would increase if there was not a substantial decrease in water availability. For Spain, the models project a medium-term decrease in the production of forests, although this would be accompanied by an increase in litter, due to the decrease in their leaf turnover time (chapter 9). A transect of European pine forests, from Scandinavia to Spain, Berg *et al*. (1999), shows that inputs of litter (of the needles fraction) linearly decreased towards the higher latitude in the range between 48 and 67° N, whereas it decreases again in Mediterranean conditions. In this transect, the drought factor probably reduces inputs into Mediterranean plots.

Increase in decomposition rate. Temperature increase affects decomposition rate more than primary production, and the net result should therefore be a decrease in soil C content (Batjes and Sombroek 1997). Initially, the work with real soils appears to confirm this prediction (see below), although the situation would probably be more complex, because if the temperature increase is accompanied by increased aridity, the decomposition rate should decrease. The results obtained in the VAMOS experiment (Bottner *et al*. 2000, Fig. 8.9) illustrate this prediction: in a transect of forest soils, from northern Sweden to the Valencia Region in eastern Spain, the translocation of organic horizons from North to South (from northern Sweden to southern Sweden and from southern Sweden to England) produced an increase in mineralisation rate, which suggests that in these latitudes, temperature is the main limiting factor. The tendency was inverted, however, in the Mediterranean area: on translocating the soil of England to the S of France and from the S of France to more arid Mediterranean zones (Lleida or Castellón) there was a decrease in decomposition rate: mean temperatures ceased to be the limiting factor for microbial activity, and water availability became the main conditioning factor.

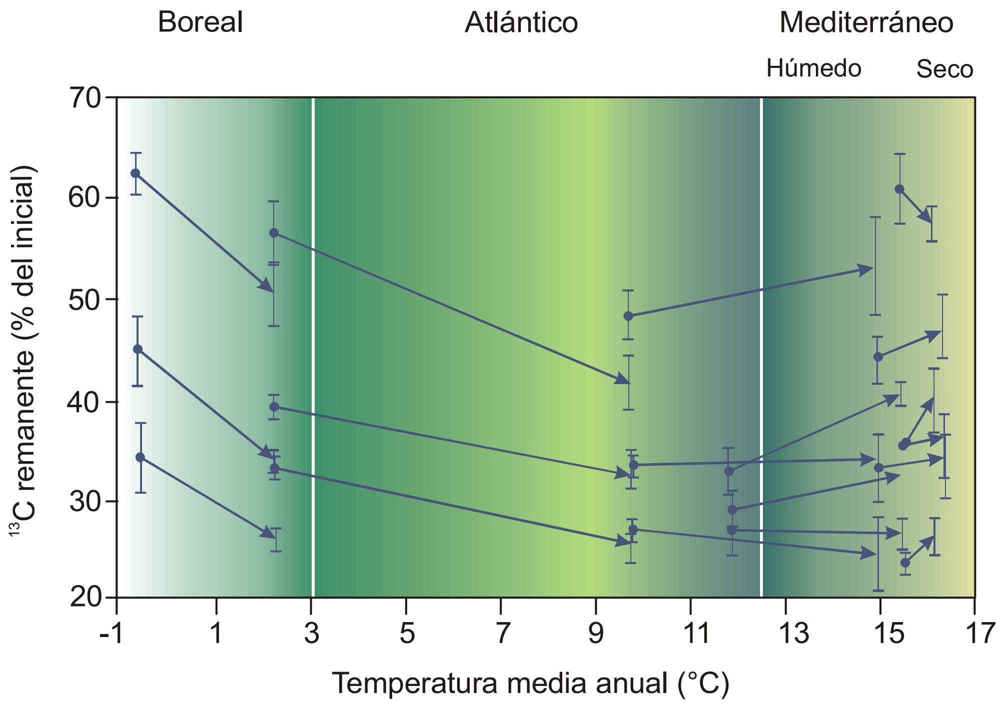


Fig. 8.9. *Labelled residual carbon (^{13}C) in the soil, following incubation, in % compared with the initial for the organic and mineral horizons of pine forests. The arrows connect the two stations subjected to the soil translocation: the origin station (circle) and the destination station (arrowhead), which was always situated further South. It can be seen that, from North to South, within the Boreal and Atlantic latitudes, there is a decrease in the % of remnant ^{13}C, which indicates an increase in decomposition rate. On changing from Atlantic to humid Mediterranean, and from humid Mediterranean to dry, the tendency is inverted, water deficit (and not temperature) becoming the main limiting factor. From Bottner et al. (2000), somewhat simplified.*

In the upper altitudes of mountain areas, icreasing temperatures and no significant reduction in precipitation would enhance microbial activities that would lead to a more rapid breakdown of the soil carbon stores of these soils.

In recent years, simulations have been made of the influence of climate change on the processes regulating soil OC content, based particularly on the determination of emissions of carbon dioxide from the soil in variable conditions of moisture and temperature. Studies carried out in the humid zone (Guntiñas *et al*. 2000) or in the Mediterranean area (Peñuelas *et al*. 2003, en prensa) show that reduced moisture decrease respiration and temperature increase also increase respiration of the soil, the effect of temperature being more evident. In any case, it was also obvious, especially in the Mediterranean area, that there is a soil moisture threshold below which the influence of temperature is irrelevant. We could therefore conclude that the effect of temperature increase as an accelerator of soil mineralisation should be seen in the humid area of Spain, whereas the opposite effect could occur in the Mediterranean. However, any increase in summer precipitation in Mediterranean conditions would have a significant increase of soil OC mineralisation (Sanz *et al*. 2004).

In short, the possible direct effects of an increase in atmospheric CO_2 (increased production, decrease in quality of litter, effects on microbial activity) are doubtful in the medium and long term, and for the time being it is reasonable to rule them out in the prediction. The effects of temperature increase are persistent and more consistent. In practical terms, it is therefore reasonable to focus the analysis on the prediction of these effects at global scale: temperature increase together with reduced rainfall.

Predictions based on computerised models

The CENTURY model is the most commonly used for prediction of OC dynamics, as it is the one that best allows climate factors and a possible change in OC quality to be integrated. We give a few examples of simulations of climate conditions similar to those in some parts of Spain.

Paustian *et al*. (1996) use the model to the simulation of agro-ecosystems in the semiarid continental area of the United States for a 50 years period. The results can be taken as a reference for the more continental areas of Spain (the Plateau). The simulation considers effects forecasted by climate change: increased photosynthesis, decreased transpiration per leaf area unit, increase in tissue C/N, increased allocation of C to the roots. The dynamics of soil OC depends more on land management than on climate change itself. Increased production of agricultural residues is predicted, which will lead to an increase in soil OC.

West *et al*. (1994) apply CENTURY to semi-desert ecosystems in the USA. The predictions could also be valid for the more arid areas of Spain (areas of Andalucia, Murcia, Alicante). In all case, a decrease in soil organic C is predicted, along with an increase in carbonates and in soil erosion. OC loss predicted for the next 40 years is between 1 and 1.25%, for a temperature increase of 2ºC, which is much less than that forecasted for other ecosystems, as we will now see.

Bottner *et al*. (1995) apply the CENTURY model to calculate carbon losses in contrasted Mediterranean conditions. The losses calculated, for a temperature increase 3ºC (without modifying rainfall) n the next century, range from 15% for very arid areas, with precipitation (P) < 100 mm (Cairo, Egypt; Bechar, Algeria), to 20% for cooler areas like Montpellier (France) or 28 % for very humid Mediterranean areas (Ain Draham, Tunisia: P = 1534 mm). These estimations would result in a loss of OC between 5 and 9.3% for each degree of temperature increase. According to the same authors, in Mediterranean conditions, there seems to be a more evident effect of water shortage on soil OC dynamics than of temperature increase.

Research based on the study of climatic transects

The method consists of studying the total organic carbon content of soils in a geographic zone and establishing generic relationships between rainfall and/or temperature and OC content. These relationships can be extrapolated to the forecasted climate change, or to a series of scenarios. A temperature increase is generally assumed, but there are doubts with regard to changes in rainfall.

Álvarez and Lavado (1998) apply this criterion to soils of the Argentine pampas. They obtained a good correlation (non-linear) between total carbon in the soil and the rainfall / temperature ratio (r^2 = 0,693). Using the relationship obtained, they extrapolated the result to a forecasted climate change. The problem lies in the uncertain evolution of rainfall. If rainfall increases, total soil OC may increase; if rainfall does not increase, however, they estimate that a temperature increase of 6ºC (considered the most likely estimate for this zone) will lead to a 45% loss of soil OC, which is around 7.5% for every ºC of increase.

With regard to Spanish soils, the work of Hontoria *et al*. (1999) is the main reference available. Using a database of published profiles, they correlate OC content of the soil with (1) land use, (2) total rainfall, (3) annual temperature and, among other parameters, (4) number of consecutive days in which the control section of soil profile is totally dry (parameter used by the USDA taxonomy to classify soils). The correlations obtained are not very high (< 0.5), which can be attributed to the heterogeneity of climate, parent material, vegetation type, etc. Using the relationships obtained, the authors extrapolated the result to four possible scenarios of climate change (Table 8.3). Of 12 possible situations, only in three cases an increase in OC content is predicted, which would be in the case of an increase in rainfall. The greatest losses of OC are obtained for a decrease in rainfall at the same time as a temperature increase, which would coincide with the most recent predictions. Possible carbon loss in agricultural soils was not calculated, but the percentage should be much lower. It should be observed that the loss is much higher in soils under grasslands, which are usually the richest in OC. Furthermore, in agricultural soils, most of the OC is associated with fine fractions (fine silt and clay), physically protected, and initially much more stable and inert than the OC in the soils of forests or grasslands.

Table 8.3. *Calculated loss of organic carbon in soils of the Iberian peninsula in different situations of climate change. According to Hontoria et al. (1999).*

Climatic Parameter		Vegetation type		
Temperature	Rainfall	Forest	Shrubland	grassland
No change	- 10 %	- 7.8 %	- 5.5 %	- 9.0 %
+ 10 %	No change	- 5.6 %	- 4.0 %	- 6.5 %
+ 10 %	+ 10 %	+ 0.8 %	+ 0.6 %	+ 0.9 %
+ 10 %	- 10 %	- 12.9 %	- 9.1 %	- 14.8 %

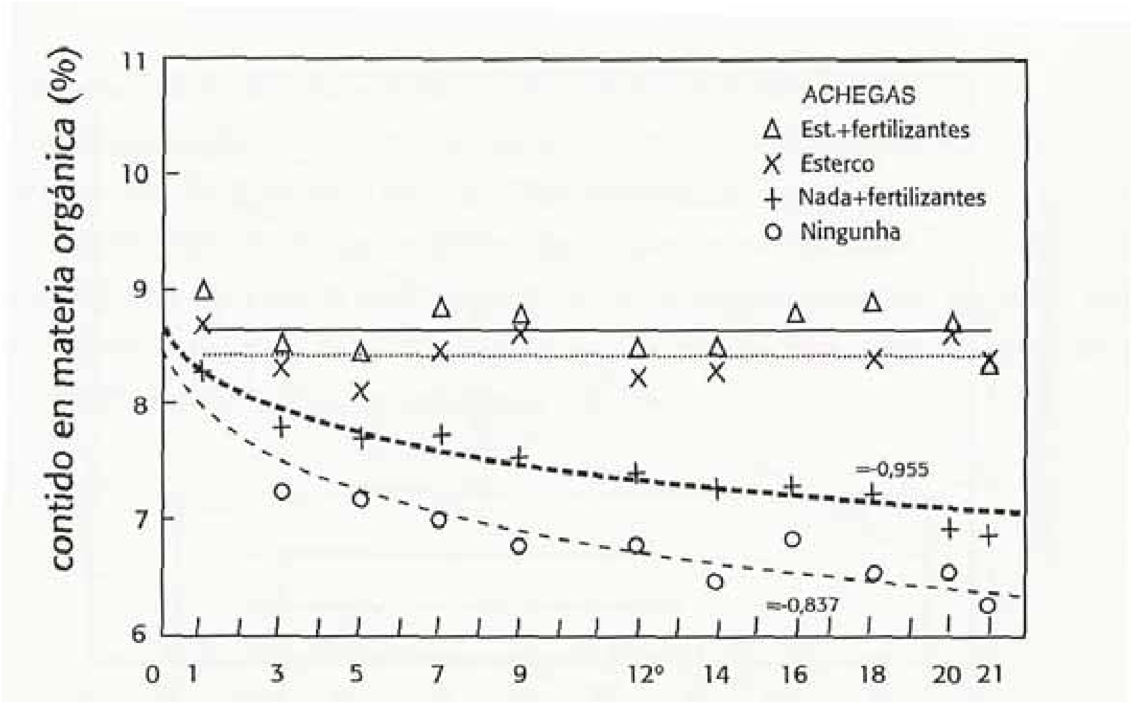
If there is no increase in rainfall, the OC content should decrease at worst by almost 15%. The biggest losses will occur if, besides a temperature rise, rainfall is also reduced. Taking Barcelona (mean temperature: 15.5°C) as an example, we see that a 10% increase in temperature would cause an increase of approximately 1.5ºC. In this case, the carbon loss would be, at worst 14.8 / 1.5 = 9.9 % for each degree of increase. In the case of shrubland, it would be, at worst, 9.1 / 1.5 = 6.1 % for each degree. This result is similar to what was obtained by Álvarez and Lavado (1998) for the Argentine pampas and consistent with the aforementioned calculation by Bottner *et al*. (1995).

The coherence of these three results (Bottner *et al.* 1995; Álvarez and Lavado 1998; Hontoria *et al. 199*9) suggests that a mean value of 6-7 % carbon loss for each degree of temperature increase could be accepted (that is approx. between 3 and 8 Mg C ha^{-1} loss per each degree of temperature increase), and that this value can increase or decrease depending on the change in rainfall and also depending on the characteristics of the soil and land uses.

Climate change can affect the different OC compartments (Coûteaux *et al.* 2000) in different ways, and carbon loss can therefore be distributed unequally in the soil. Contrary to what might be expected, in our soils, the OC of the deep part of the profile is often less stable than that of the top soil. Although the physically protected carbon percentage is higher in deeper soil horizons, it is also relatively richer in carbohydrates and less so in recalcitrant fractions (Rovira 2001). Given that the deep soil is more likely to be able to maintain moisture throughout the summer, it is possibly the carbon from the deep soil horizonsof the fraction that suffers the greatest loss. This is uncertain, however, as Bol *et al.* (2003) recently verified that it is the most recalcitrant and oldest OC fraction that responds most clearly to a temperature increase.

8.3.4. Changes in land use

Changes in land uses and management, along with the occurrence of disturbance, such as wildfires, affect soil OC content. Of great interest, because of its duration, is the study carried out in Pontevedra (Sánchez and Dios 1995) on the evolution of soil OC in a plot of corn subjected to different systems of fertilisation over a period of 21 years. The results (Fig. 8.10) shows how the plot in which organic fertiliser was suppressed underwent a progressive decrease in OC content, which, at the end of the study period, reached 30% reduction. Another study, also carried out in the humid part of Spain, based on the analysis of three soil maps made in different years (1958 1964 and 1997) shows how the soils used for corn, with little or no organic fertilisation, lost 43% of their initial OC content in 39 years. Furthermore, comparison of the mean soil OC content in humid areas of forests or shrubland with croplands of potato or cereal always present a decrease in OC content which is between 30-40% (Calvo de Anta *et al.* 1992). In a Mediterranean area, the OC content of the soil in a pine forest, 9 years after clearcutting, changed from 2.34 % to 1.61%, this loss mainly being due to mineralisation and by less than 1% to soil erosion (Martinez Mena *et al.* 2002).



Years after treatments application

Fig. 8.10. *Evolution of the organic matter content of a soil used for maize in the Misión Biológica, CSIC (Pontevedra, Sánchez and Dios 1995) with different treatments (0 none, + mineral fertilisation, x organic fertilisation, ∆ mineral + organic fertilisation). % Organic matter/1.724 = % OC.*

The ploughing of forest soils always leads to loss of soil OC (for example, Fig. 8.11). The figure shows that recovery of the initial levels, in sandy soils as in this case, can be relatively rapid (around 80 years in the abandoned and afforested cereal fields) and even more so when a fast-growing species is introduced (*Pinus radiata* in this case). When the soils have suffered losses by erosion, however (vineyard soils on slopes), the recovery is slower.

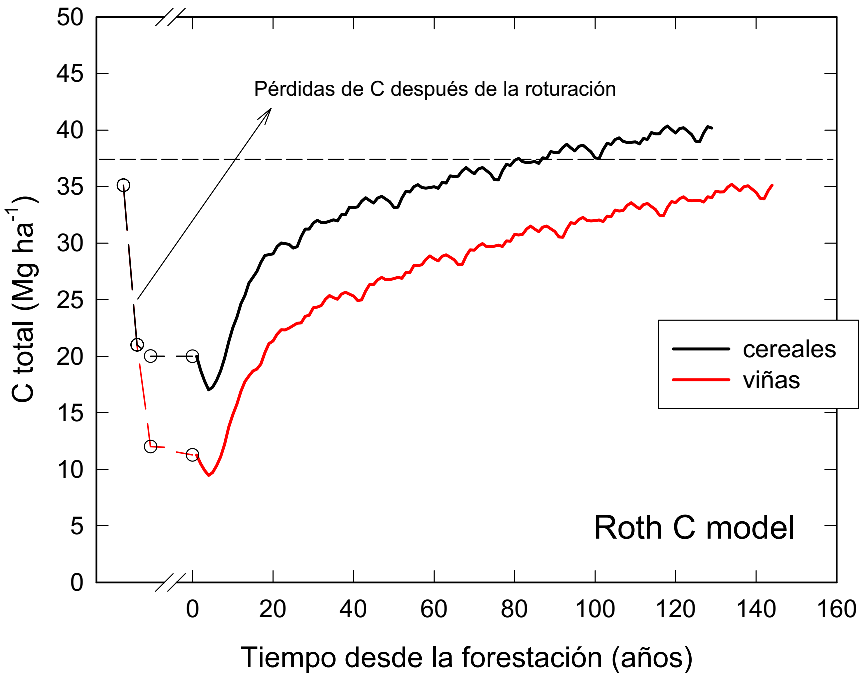


Fig. 8.11. *Changes in soil OC following ploughing and afforestation with Pinus radiata in Mediterranean conditions according to the Roth C model. The broken line refers to the carbon levels of the autochthonous Holm oak forest (Romanyà et al. 2000).*

Lastly, accidental disturbances such as forest fires that may increase as a consequence of climate change (Piñol *et al*. 1998) are likely to cause losses of soil OC content which can range from values of less than 5%, when temperatures are below 170ºC, to higher than 90% when they are over 450ºC (Soto*et al*. 1991) in the top few cm of the soil. During a forest fire, a large amount of CO_2 is released into the atmosphere, but as the affected ecosystem grows again and recovers, the CO_2 is captured and fixed via photosynthesis, and incorporated into the system once again; it can therefore be considered that the medium-term net C balance is zero (Levine 1996), when soil erosion is not significant. During fires, however, changes occur in the dynamics of the organic matter, giving rise to the creation of more degradation-resistant forms and therefore to C sequestration processes in the geosphere (González-Vila and Almendros 2003; González-Pérez *et al*. 2004). This effect can be particularly relevant in regions like the Mediterranean basin, where forest and vegetation fires are a recurring phenomenon. The production of this type of refractory OC in Andalucia has been estimated at up to 31,000 t/year (González *et al*. 2002). As a consequence of the high temperatures generated by the fire, hydrophoby is occasionally created on the surface or subsurface layers of the soil, which reduces water infiltration with the consequent negative effects on surface runoff (which substantially increase up to values of over 20% of rainfall, Soto and Díaz-Fierros 1998) and water content of the soil. In fine-textured soils, especially when the silt fraction predominates, the temporal loss of vegetation cover caused by the fire creates a surface crust which reduces infiltration of water into the soil and increases runoff (and the risk of flooding) (Bautista *et al*. 1996).

In summary, forest fires often produce OC losses in the top soil. These losses may be partly counteracted by the formation of recalcitrant OC compunds during combustion. Plant regeneration may re-establish OC balance in the medium/short-term. Finally, soil physio-chemical changes induced by forest fires may increase soil erosion and runoff, and limit plant recovery.

8.3.5. Synthesis of the effects of climate change in soil OC

Soil OC results from the balance between inputs – input of litter (or organic amendments in crops), including dead roots, and outputs – decomposition (plus lixiviate of soluble OC). In forest ecosystems, litter inputs could increase according to the models estimates (chapter 9), although, on comparing climatic transects of current forests, it appears that drought reduces these litter inputs. Furthermore, in multi-temporal studies of Holm oak forests in Catalonia, litter production is related in a linear and significant way to the net primary production of the aerial part of the forest (Ibáñez *et al*. 1999). In wet conditions (North of Spain), an increase in inputs is to be expected, but in the dry part of Spain, this aspect remains quite uncertain. With regard to decomposition rate, all studies coincide in that it accelerates with temperature increase, unless there are increased drought conditions (Fig. 8.9), in which case the decomposition rate would be reduced. In Mediterranean conditions, soil respiration and OC mineralisation are limited by temperature in winter and by drought in summer (Casals *et al*. 2000, Rey *et al*. 2002). According to the latter authors, a general decrease in soil respiration is to be expected in the climate change scenarios accepted for Mediterranean conditions. The projected changes would therefore cause an increase in decomposition rate in humid Spain and a decrease in Mediterranean Spain.

OC cycling models and studies of climatic transects (Table 8.3) suggest a decrease in soil OC as a consequence of the increase in temperature and drought. The data from the transects are quite consistent, as they are based on direct analyses of soil OC. These data are not compatible, however, with an increase in inputs and a decrease in decomposition rate, assumed in the previous paragraph for the Mediterranean region. We could therefore expect that there would more likely be a general decrease in soil OC content, which in the Mediterranean areas would be determined by reduced litter inputs, with the uncertainty associated with this process.

8.3.6. Effects of climate change on the microbial and faunistic community of the soil

The organisms in the soil are very much influenced by plant cover in general, hence alterations are to be expected in the composition of communities of organisms in the soil in consonance with changes in land uses and those derived from climate change.

Microbial flora

According to Panikov (1999), the microflora is adapted to survive large temperature changes in the soil (day-night changes of tens of degrees in summer; also large seasonal changes) and in water content (great seasonality in the Mediterranean climate); these changes are of a greater magnitude than predicted increases in mean temperature or increases or decreases for rainfall. The direct effects should therefore not be very significant. The results obtained by Moscatelli *et al*. (2001) in Mediterranean soils tally with this prediction: microbial activity exposed to an atmosphere enriched in CO_2 returns to the level of the control soils in barely two years. This could be due to the great redundancy of the microbial community; many different taxa appear to occupy the same ecological niche, competing for the same substrates. Some of these may be favoured by climate change, while others could be negatively affected; in any case, there are always taxa prepared to take over the function of those negatively affected. Even if we assume that microbial diversity would be harmed (which is yet to be proven), it is not clear that this would affect the functioning of the soil in the global ecosystem. This is the result of most of the studies in which the microbial biodiverity of the soil was artificially reduced, through fumigation or irradiation.

With a temperature rise, there is an increase in respiration, but the effect depends on the nutritional state of the soil, and is less evident in oligotrophic soils. The increase in respiration is due to the activity of the microflora, because the temperature increase causes a decrease in microbial biomass (Álvarez *et al*. 1995). In the case of non-agricultural soils, impoverished in nutrients, microbial activity would be less affected by the temperature increase, and it is therefore the soils rich in OC (which also tend to be the ones rich in N and P) which are most threatened.

Soil fauna

As a whole, the effects of climate change on the fauna of the soil are much less predictable than the effects on the stocks of organic carbon. There are quite many studies carried out in microcosms, but the diversity of the results makes it difficult to establish a clear pattern It is usually accepted that an increase in atmospheric CO_2 alone would have little effect on the soil fauna in the soil because this fauna is already adapted to the soil atmosphere which is very rich in CO_2 (Van Veen *et al*. 1991). However, Zaller and Arnone (1997) observed an increase in activity of earthworms in soils subjected to a CO_2 enriched atmosphere. If this were to be confirmed, these results would be of great relevance because of the important role played by earthworms in the maintenance of the natural fertility of soils and in OC dynamics.

Few studies in which soil temperature was artificially raised in field conditions showed an increase in the biomass and diversity of the mesofauna, provided that there was not an excessive decrease in water availability: if this occurs, the effect becomes negative (Harte *et al.* 1996).

Species unable of resisting prolonged summer droughts can be expected to disappear. It is unclear what effects this disappearance can have on the functioning of the soil as a global system. The effect may not be great because the trophic web of the soil is highly redundant, with a number of species much greater than what is needed for the efficient functioning of the biogeochemical cycles (Freckman *et al*. 1997). In any case, the simplification of the animal community of the soil should provoke the acceleration of biogeochemical cycles, because a rich and complex trophic web reduces the intensity of OC decomposition, due to the depredation the decomposing organisms are subjected to (bacteria, fungi, actinomycetes) by micro- (protozoans, nematodes) and mesofauna (microarthropods) (Setälä and Huhta 1990, Scheu and Wolters 1991).

8.3.7. Soil fertility

As a result of the intensification of agriculture and of the changes in land uses that have occurred since the middle of the XX century, the fertility of European soils is currently in a dichotomy. Whereas the intrinsic fertility of agricultural soils at present has decreased (see for example the generalised loss of OC in English soils, Ministry of Agriculture Fisheries and Food, United Kingdom) forest soils, resulting from the abandonment of agriculture, recover fertility and physical properties, with an increase in OC concentration in the surface horizons (Romanyà *et al*. 2000), provided that the climatic conditions of the site have permitted sufficient recovery of the vegetation. In semiarid climates, it is frequent that the quality of abandoned soils has been insufficient to sustain the development of a minimum plant community and to initiate a recovery process. In these cases, a spiral of soil degradation would be initiated which would not allow for the autogenic recovery of soil fertility. Furthermore, in the case of old forest soils, there may be a general increase in nutrient demand as a result of the increase in atmospheric CO_2, which will depend on the species considered (Peñuelas *et al*. 2001). This differential increase, according to species, in the demand for nutrients, may, on one hand, determine the future composition of ecosystems, and on the other, reduce the quality of the litter produced. With regard to nitrogen, changes in atmospheric deposition, in some cases associated with pollution, could counteract the increased demand by the vegetation.

In this section we discuss aspects of atmospheric pollution not directly linked to climate change but that may strongly affect the impacts of climate change in the soil fertiliy. Atmospheric deposition have increased the nitrogen input to ecosystems throughout the world in general. This effect is the result of the increase in nitrogen oxides in the atmosphere caused by industry and transport activities and to intensive agriculture and livestock farming (Vitousek *et al*. 1997). In the Mediterranean, these increases have also been noteworthy, although in the last 15 years, according to data from the Montseny area (Barcelona), they have remained relatively constant, between 15 and 22 kg N ha^{-1} $year^{-1}$, whereas in the same period, sulphur has decreased (Rodà *et al*. 2002). Other measurements taken in Mediterranean areas further away from the large urban concentrations have provided values of atmospheric inputs of between 3 and 10 kg N ha^{-1} $year^{-1}$ (Bellot J. and Escarré 1991, Moreno and Gallardo 2002, Sanz *et al*. 2002). The highest values include wet and dry deposition (Sanz *et al*. 2002). The studies carried out in the Atlantic areas of Spain present higher minimum values than in the Mediterranean and maximum values that coincide with Montseny (from 11 to 22 kg N ha^{-1} $year^{-1}$; Amezaga *et al*. 1997; Fernández-Sanjurjo *et al*. 1997). Camarero and Catalán (1993) found less acidity and less nutrient deposition in rains of the Pyrenees, compared to the Alps, with greater nutrient deposition in the rainier areas. In more recent studies, apart from greater inputs of N and of organic pollutants in the rainier areas of the Pyrenees, coinciding with the higher altitudes (Carrera *et al*. 2002) and along the crests, signs of significant inputs of potentially toxic elements have been found both in soils and in sediments (McGee and Vallejo 1996; Camarero *et al*. 1998).
The low concentration of atmospheric inputs measured in the Sierra de Gata mountains (6 kg N ha^{-1} $year^{-1}$) contribute positively to the nutrition of deciduous oak forests in the area (Moreno and Gallardo 2002), although inputs of other nutrients like S and Zn are greater than the demand of the forest. Due to the high production rates of Atlantic forest and meadow ecosystems, it seems reasonable to think that the moderate inputs of N in some of these areas (20 kg ha^{-1} $year^{-1}$) could be partly absorbed by the vegetation. Even in the case of quite unproductive ecosystems, for instance the heaths of *Calluna vulgaris* in the NW of the Peninsula, it has been seen that the vegetation is capable of recycling amounts of N greater than those deposited by the atmosphere (Marcos *et al*. 2003). Mediterranean Holm oak forests are able of internally recycling the highest amounts of N in atmospheric deposition measured in Spain (20 kg ha^{-1}). Given that the growth rate of the Holm oaks is not sufficient to consume all this N, it seems that much of the deposited N is temporarily retained in the soil (Rodà *et al*. 2002). The more long-term fate of this N in these Holm oak forests remains unclear. In Mediterranean shrublands, N mineralisations have been measured of between 20 and 40 kg ha^{-1} $year^{-1}$, whereas in dry grasslands, mineralisation is clearly higher (40-70 kg ha^{-1} $year^{-1}$; Romanyà *et al*. 2001). These data suggest that in Mediterranean shrublands, atmospheric deposition can double the amount of available N, and can therefore lead to big changes in the nitrogen dynamics. In agricultural ecosystems, the inputs of atmospheric N, although it may be lower than the demand of most crops, could contribute to overfertilisation.

Given that the atmospheric deposition of phosphorous is very low (Vallejo *et al*. 1998), the atmospheric inputs of N may result in a greater relevance of phosphorous limitation in terrestrial ecosystems. There is quite a lot of evidence of a general limitation of phosphorous in Mediterranean forest ecosystems, at least for carbonated soils (Vallejo *et al*. 1998). Analysis of tree nutrition in the forest inventory of Catalonia, using the DRIS system, indicated a generalised phosphorous deficit in the pine forests of regions dominated by carbonated soils (Serrano, unpublished data). Furthermore, fertilisation tests with forest seedlings on carbonated lutites have also shown a positive response of phosphorous nutrition to fertilisation with sewage sludge (Valdecantos 2001). In Atlantic forest soils, the availability of P also appears to be a key factor in the nutrition of plantations of *Pinus radiata*, especially in soils with very acidic pHs (Romanyà and Vallejo 1995; Sánchez-Rodríguez *et al*. 2002; Romanyà and Vallejo 2004). The increased availability of nitrogen associated with atmospheric pollution could result in increased demand for phosphorous, thus exacerbating the deficit of the latter. Furthermore, both the high levels of available nitrogen and the lack of phosphorous could hinder N_2 fixation (Binkley and Giardina 1997) and therefore favour the development of non-N fixing plants.

With regard to the possible impact of pollutants, using the Pantanal model (MicroLEIS DSS; de la Rosa *et al*. 2004) and assuming a foreseeable climatic disturbance for the year 2050, it was seen that the risk of diffuse pollution in soils in Andalucia, resulting from the use of nitrogen and phosphated fertilisers, heavy metals and pesticides, increases in 60% of the soil surface, whereas it decreases in 40% of the area. The former soils are located on the coast of Cadiz and in the highlands of Jaen. The soils in which the risk of pollution decreases are located mainly in the lowlands of Cordoba, the Huelva and Malaga coasts, and in the best agricultural areas of the province of Seville. Considering each type of pollutant separately, the risks constituted by heavy metals and pesticides are proportionally greater than the risks caused by the use of fertilisers (de la Rosa *et al*. 1996).

8.3.8. Impacts on the physical degradation of the soil and soil erosion

The physical properties of the soil can be particularly altered by certain types of land management and by fires, and in general by the loss of OC, which is an essential factor of soil structure. The degradation of the physical properties may lead to soil sealing and surface crusting, compaction, incresed hydrophoby of soil surface, loss of structural stability, decreased infiltration capacity (which exacerbates drought conditions) and increased stress through cracking in vertisols.

In conditions of climate change, mean rainfall can be expected to decrease, and extreme events can be expected to be much more frequent. This could bring about a dangerous increase in soil erosion in vast areas of the country.

Considering the EC climate scenario for the year 2050, the risk of erosion of the EU's agricultural soils is expected to increase by 80% (UNEP-EEA 2000). This increase would mainly be in the areas that already present a severe risk. According to the same sources, a 20% increase is expected in relation to the agricultural area in Spain threatened by a very high risk of erosion, whereas the areas with high and moderate risk levels would decrease by 8 and 19%, respectively.

The influence of rainfall on the erosivlity of soils can be estimated by using factor R of the USLE model, or with the use of more simple relationships that base the estimate on monthly or annual rainfall values (Renard *et al*. 1994). Nearing, *et al*. (2004), applying the WEEP model to soils characteristic of the USA, determined that for each 1% increase in annual rainfall, there is a 2% increase in surface runoff and that erosion increases by 1.7%. The lower sensitivity of erosion than runoff to change is due to the fact that the soil is protected by the increase in aboveground biomass, resulting from increased rainfall. Rainfall intensity is also expected to increase in accordance with the intensification of the hydrological cycle which is expected to cause global warming.

Furthermore, as a consequence of the increase in temperatures and in summer drought predicted for Mediterranean areas, it is believed that there will also be a greater incidence of forest fires, and the changes that these will cause in relation to the soil erodibility and vegetation protection of the soil will therefore be added to those generated by the increased erosivity due to rainfall. At the same time, the decreased soil OC content will also have the same effect, that is, increased soil erodibility (factor K of the USLE).

In the case of Andalucia, making use of the Raizal model (MicroLEIS DSS; de la Rosa *et al*. 2004) and assuming a foreseeable climatic disturbance for the year 2050, it was found that the risk of water erosion increases in 47% of soils, although it decreases in 18% of the soils in other areas. The former soils are located in the Northeast of Almeria, the northern mountains of Cordoba, the Northwest of the Granada province and southern Jaen. The soils in which the risk of erosion decreases are mainly located in the southern mountains of Cordoba, the centre of the province of Granada and northern Jaen, and in the best agricultural areas of the province of Seville (de la Rosa *et al*. 1996). However, land use change as a response to climate change may significantly modify erosion impacts, e.g. through the introduction of new crops and new management practices, or promoting land abandonment.

Table 8.4. *Summary of the results of the evaluation of erosion risk in Andalucia, for the present climate situation (1961-1990) and for the climate disturbance predicted for the year 2050 (temperature increase and reduced rainfall). Source:* de la Rosa *et al. (1996)*

Type of vulnerability	Present scenario		Change scenario	
	km^2	%	km^2	%
V1. None	4253	5	4253	5
V2. Very low	3906	4	6219	7
V3. Low	14643	17	13285	15
V4. Moderately low	13918	16	12963	15
V5. Slightly low	5177	6	5247	6
V6. Slightly high	21219	24	20952	24
V7. Moderately high	10573	12	5826	7
V8. High	7887	9	12569	14
V9. Very high	4925	6	3560	4
V10. Extreme	773	1	2400	3

The application of the suppositions of climate change in chapter 1 of this report to the estimate of erosion risk using the USLE, in the Valencia Regional Autonomy (Fig. 8.12 and 8.13) only produces moderate increases in the risk of extreme erosion, by between 5 and 6%.

Separate consideration should be given to the changes in uses and vegetation types that could be caused by climate change. Changes in uses, particularly when they evolve from forest and shrubland to intensive cropping, have a clear negative effect in relation to risks of soil erosion. In addition, the predicted tendencies of change towards enhanced Mediterranean-type features in forest and shrubland would clearly influence the risk of fire, which would logically increase.

Finally, with regard to the series of processes of physical degradation of the soil (e.g. compaction), it ought to be pointed out that maintaining therein OC levels higher than 2.3% is the best method of protection against this type of degradation. If we consider that this soil OC threshold is practically equivalent to a carbon content 8 $kg.m^{-2}$ and that many Spanish soils are below this value (Figure 8.7) we could conclude that the risk of physical degradation of the soil should increase according to the expected decrease in soil OC due to climate change.

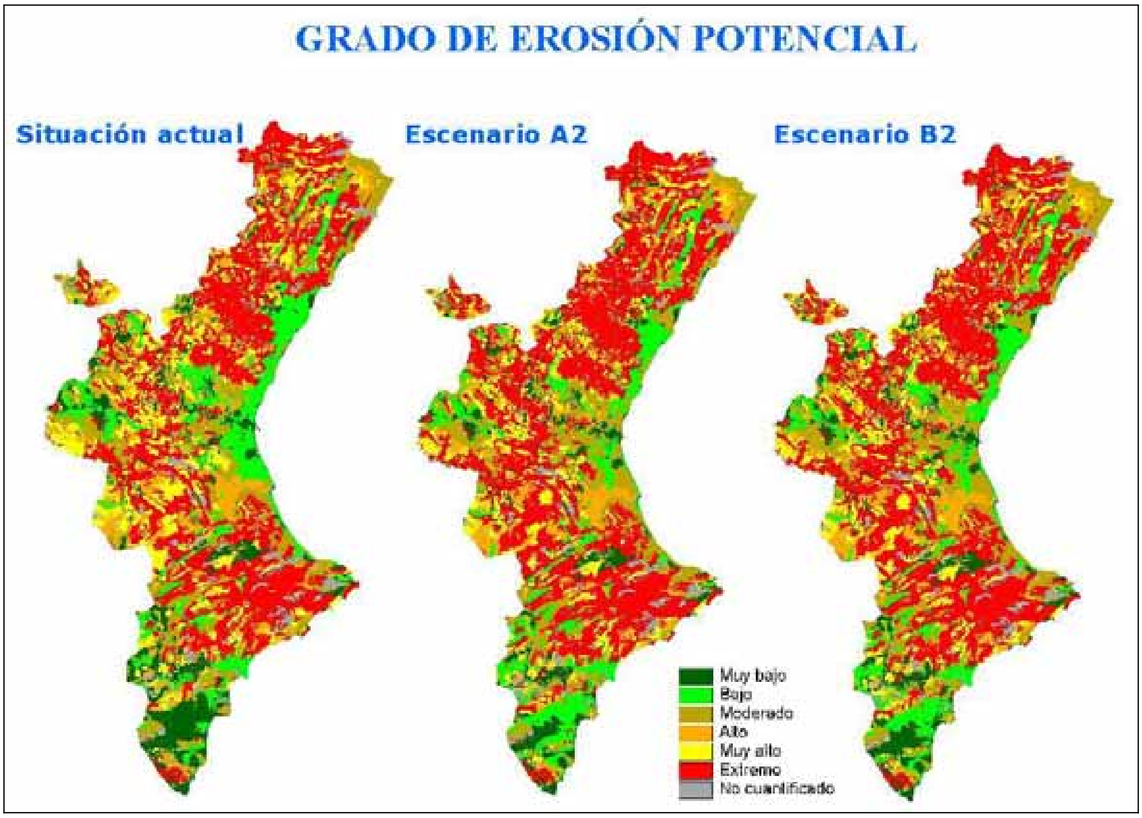


Fig. 8.12. *Estimation of the degree of erosion according to the predictions of climate change for the Valencia Regional Autonomy. Factor R has been modified (erosivity of rainfall in USLE model) in accordance with the predictions of changes in rainfall regime.*

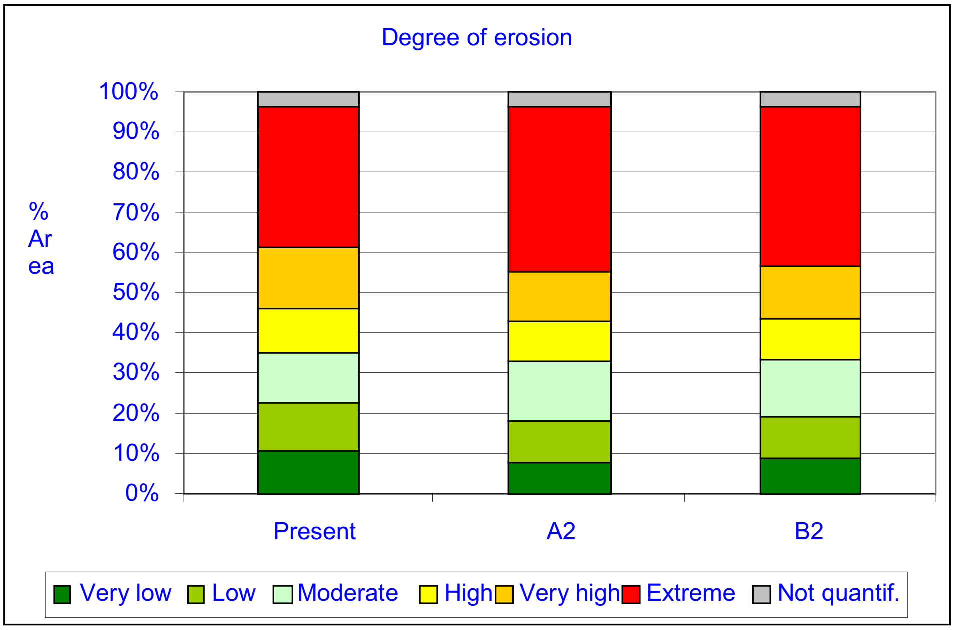


Fig. 8.13. *Percentage of area affected in the Valencia Regional Autonomy by different degree of soil erosion (data from Fig. 8.12) for socioeconomic scenarios A2 and B2. The area affected by the "extreme" degree would increase by between 5 and 6%, whereas the set of degrees "high + very high + extreme" would only increase by 2 %.*

8.4. MOST VULNERABLE AREAS

The most vulnerable areas are those that are most affected by processes of desertification (Fig. 8.3, 8.4 and 8.5, including the predicted increases in forest fires, chapter 12), which are expected to be accentuated in the assumed increases in aridity of the climate.

With regard to the change in OC content, the areas in which the greatest losses are to be expected would be the more humid ones (North of Spain) as well as the land uses that promote higher soil OC contents (meadows and forests). In the driest areas, small OC losses may drive crossing critical thresholds for the maintenance of essential soil functions.

8.5. MAIN ADAPTATIONAL OPTIONS

In relation to the possibilities of improving carbon fixation, the measures considered by the IPCC include: crop management aimed at producing greater C inputs to the soil, irrigation management, conservation agriculture, erosion control, ricefield management, grazing management, increased productivity of pastures, fire management in pastures, forest regeneration, restoration of old wetlands and restoration of very degraded soils.

8.5.1. Influence of agricultural practices

The sustainable land use and management systems have great potential for carbon sequestration in agricultural lands by means of the reduction of soil organic carbon losses and increased biomass production (Lal and Kimble 1998). It is estimated that farmed soils contain, in general terms, between 20 and 40 % less OC than unfarmed ones (Davidson and Ackerman 1993). The loss of OC in agricultural soils can be recovered by means of the application of appropriate management practices (Lal *et al*. 1998). According to estimates by the FAO (2002) for the year 2030, the amount of OC fixed in agricultural soils, as organic matter from crop residues and manure, may increase by 50% if the corresponding management practices are introduced. OC lost from the onset of agriculture is estimated between 40 and 90 Pg C (Raupach *et al*. 2003). Annual rate of OC recovery through changes in agricultural management could be of the order of 0.3 to 0.9 $PgC \cdot y^{-1}$ (Lal 2004, Smith 2004). Therefore, some 50 to 100 years will be required to compensate those OC losses, in the better possible scenario.

With regard to land use type, the best fit between the potentialities and limitations of the different soils, and the soil requirements of the possible crops, should be attained. To this end, agro-ecological zoning constitutes a previous and indispensable study in any area or region. The diversification of crops will be conditioned by these studies of spatial variability of soils and climate. In turn, the detailed segregation of vulnerable or marginal areas for agriculture will be a consequence of agro-ecological zoning.

Agricultural management has a significant influence on the amount of carbon stored by soils over time. Certain changes in agricultural practices can determine how much and how fast carbon is stored or released by soils (Ringius 1999). The environmental sustainability of agricultural practices, adapted to the agro-ecological conditions of each area, refers especially to the following aspects: restoration of the soil organic matter content, intensity and direction of tilling, consideration of soil moisture for each operation, type and weight of the machinery to be used in order to avoid compaction, and rationalisation of the use of fertilisers and pesticides.

Agriculture adapted to each soil type, placing particular emphasis on maximising the production of crop residues, to be incorporated into the soil, and on reducing and diversifying tilling, will facilitate the sequestration of soil OC, along with all the other associated benefits relating to physical, chemical and biological soil properties. Furthermore, the maximum use of crop residues is a very efficient method of erosion control. Conservation agriculture (reduced tilling with recycling of crop residues in the form of mulching) is very effective for controlling erosion and also involves considerable savings on fuel. These practices are slowly but steadily expanding in Spain.

In the recovery of degraded soils, the level of carbon sequestration can serve as an indicator of this recovery: thus, if degradation decreases, sequestration increases, and vice versa. In semiarid areas of the world, it has been estimated for the next 50 years that if effective conservation and soil rehabilitation measures are implemented, an annual carbon sequestration rate will be reached between 1.0 and 1.3 Gt per year (Squires 1998). Fig. 8.14 shows the distribution of agricultural soils with ochric epipedon, the properties of which would be improved with the addition of organic amendments. The ochric epipedon is defined by properties that are initially associated with OC content (Soil Taxonomy), such as a more or less dark colour and structure. There are, however, agricultural soils with ochric epipedon in northern Spain which have high OC contents, which means that in this case properties are not necessarily improved by adding organic amendments.

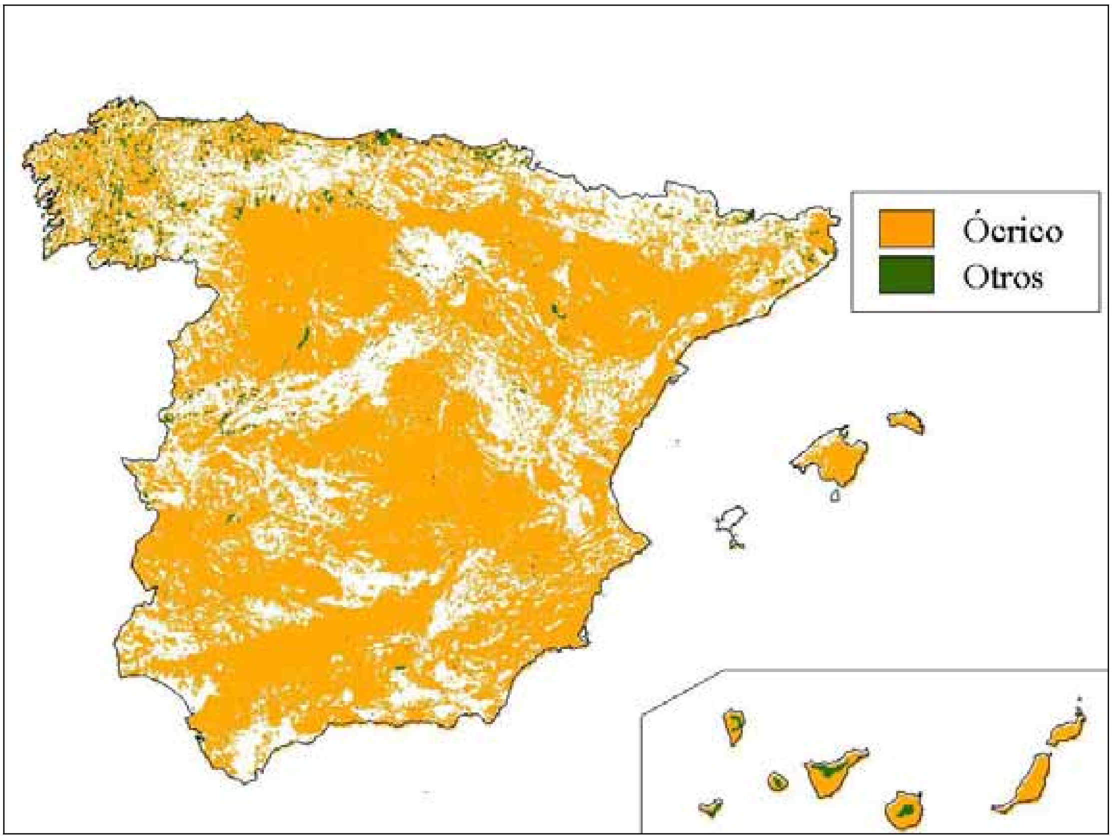


Fig. 8.14. *Agricultural area on soils with ochric epipedon the quality of which could be improved with the addition of organic amendments (96 % of the area used for agriculture in Spain). Map based on cartography of land uses CORINE from 1991 and from the IGN soils map from 1992.*

8.5.2. Abandonment of croplands

At the present time, both the structure and the dynamics of Mediterranean wildlands bear the effects of old land uses. The large areas occupied by colonising vegetation, basically in abandoned agricultural areas, have led a great amount of our forest soils to aggradation phases, whereas in areas in which forest productivity is severely limited (for instance in areas with a high recurrence of forest fires or in semiarid climates) degradative processes can prevail.

Abandoning unproductive croplands provides the opportunity to increase carbon sequestration by turning them into forest or shrubland. In semiarid climates, however, abandonment can lead to greater degradation if the restoration of the ecosystems is not managed. In dry sub-humid Mediterranean climatic conditions, the greater production of vegetation biomass and fuel favours the spread of forest fires. The abandonment of crops therefore provides management possibilities for counteracting the impacts of climate change and also for avoiding the degradation of abandoned lands.

8.5.3. Afforestation/reforestation

One of the main objectives of the afforestation plans of Mediterranean countries is soil protection. Indeed, large forest restoration projects have been documented in Spain since the end of the XIX century, aimed at protecting basins that were frequently flooded (Gómez 1992).

In early stages of succession, soil is a critical factor that controls the development of ecosystems (Bradshaw 1997). In situations in which soil cover is very low (less than 30%), a cycle of degradation can be initiated. In these situations, actions should be implemented aimed either at directly improving the soil (application of organic amendments, mulching) and/or at introducing herbaceous or woody species (sowing, plantations, introduction of mycorrised plants) which, through synergy, can reverse the soil degradation process (Vallejo *et al*. 2003). Revegetation is the most efficient means of controlling soil degradation in barren lands. The insufficient availability of water characteristic of the Mediterranean climate could be exacerbated in a context of degraded soils, which favours the formation of a surface crust (Maestre *et al*. 2002) and loss of structure (Caravaca *et al*. 2002) of the soil, which hinder infiltration and the capacity to retain water. In agricultural soils the formation of the surface crust can reduce the productivity of the crops (Amezketa *et al*. 2003). For these reasons, both the agricultural management of Mediterranean soils and projects aimed at the restoration and recovery of degraded soils focus at improving the physical properties of the soil (Caravaca *et al*. 2002, Bellot *et al*. 2001, Querejeta *et al*. 2000). However, inappropriate restoration practices could result in deletereous effects on soil quality and conservation.

Introducing determined species is known to favour soil conditions. On occasions, these species can even facilitate the establishment of other species within their area of influence (facilitation) (Pugnaire *et al*. 1996, Maestre *et al*. 2001, Castro *et al*. 2002, Caravaca *et al*. 2003a). The joint use of organic amendments with the introduction of plants has facilitated the recovery of the vegetation and, finally, has contributed to improvement of the soils. In some cases, it has been seen that the introduction of target organisms (e.g. inoculation of mycorrhiza) can slightly improve the results of applying only organic amendments, with regard both to the growth of the plants and to soil quality (García *et al*. 2000, Caravaca *et al*. 2002, Caravaca *et al*. 2003b).

Macías *et al*. (2001) have demonstrated the efficiency of revegetation with fast-growing species (eucalyptus) in C sequestration in quarry spoils.

8.6. REPERCUSSIONS FOR OTHER SECTORS

As the soil is the basic support of primary production, the degradation thereof will have a considerable impact on the functioning of terrestrial ecosystems, including agriculture, livestock farming and forestry production sectors. Furthermore, when the degradation is severe, it becomes irreversible, and huge investments of energy are required to recover the productivity of the soils. Apart from the direct impact on terrestrial ecosystems, soil degradation in the form of erosion, sainisation or pollution can have negative impacts on other systems, such as continental waters (siltation in reservoirs, for instance) and public works.

8.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

Most of the analyses made throughout the chapter present a varying degree of uncertainty. Table 8.5 summarises the degree of reliability of the impacts.

Table 8.5. *Synthesis of the foreseeable direct impacts of climate change on soils and associated degree of reliability. (vr): very reliable, (ir): intermediate reliability, (i): uncertain. (u); + : the impact involves an increase; -: the impact involves a decrease; 0: no significant effect is expected.*

Variables associated with climate change	Organic carbon content	Soil erosion	Salinisation	Microflora and fauna biomass and activity	Fertility
Increase in CO_2	+ (u)	-(u)	0 (vr)	0 (ir)	- (u)
Temperature increase	- (vr)	+ (u)	+(vr)	- (u)	+ (u)
Increased drought	- (vr)	+ (vr)	+(vr)	- (ir)	- (u)

Apart from the uncertainties associated with climatic and socioeconomic projections, in direct reference to soils, we can highlight:

- The impacts of climate change on soils interact in a very significant way with land uses and management. These interactions, along with the evolution of the socioeconomic factors that will regulate the types of use and management practices, constitute big uncertainties.
- Many basic studies used to estimate the impact of climate change on the production capacity and the risks of degradation of soils have been carried out in other countries in similar conditions. The degree of applicability of these observations to the conditions of Spanish soils is therefore uncertain.

8.8. DETECTING CHANGE

In Spain, there are not many studies that can provide data on the soil processes associated with climate change, although the possibility exists of analysing and interpreting certain historic soils archives, which could provide valuable information on the change tendencies of soil OC contents. Data are available from the years 1940-50, when cartographic studies of soils were carried out at a scale of 1:50.000, showing sampling sites and tabulations of OC contents. Subsequently, around the 60-70s, other soil cartography studies were made (e.g. the agrological maps by MAPA) which also present sampling and tables of data on Spanish soils. Finally, in the 90s, the LUCDEME Project designed systematic cartography of Spanish soils in the Mediterranean semiarid area. If we add to this the innumerable local or regional studies from the last fifty years, we would have a great deal of data, which, duly analysed and processed, could provide valuable information on the change tendencies of soil OC content under different climate conditions and types of use and management. The network of permanent experimental stations (RESEL, Rojo and Sänchez 1996) run by the Environment Ministry, is a very useful initiative in this sense.

Suggestions for improving follow-up

There are abundant local databases of soil characterisation, referring in particular to the results of agricultural analyses. The difficulty lies in their dissemination, their inaccessibility and that the format of the data will be heterogeneous and hard to compute. The homogenisation of this information would be of great value for increasing our knowledge of Spanish soils. To this end, the use of universal databases is recommended, such as the FAO-CSIC (2003) database, SDBmPlus: Multilingual Soil Profile Database, for the collection of information on soil profiles (data and metadata).

There are no sufficiently old and continuos studies for monitoring aimed at establishing tendencies of soil evolution or soil degradation. There exists, however, a contrasted experience dealing with the application and validity of different models that predict erosion with the use of climatic, soil and land use parameters, such as the models USLE, RUSLE, EUROSEM, LISEM, KYNEROS, WEPP, etc. To this end, knowing the expected evolution of these parameters in conditions of climate change, it would be possible to make predictions of erosion with a reasonable degree of certainty. Greater attention should therefore be paid and support given to the few long-term experiments existing in Spain, and to the maintenance of the collections of soil samples.

In relation to soil OC monitoring, the complex interactions between the effects of climate and land use change, together with the intrinsic spatial heterogeneity of soil OC, make the detection of changes very difficult, especially those related to climate change which are expected to have slowlier impacts. Therefore, the detection of change in soil OC would require long-term approaches, and the stratification of permanent sites both considering climate and land use gradients. Sampling intervals of at least 10 years would be requiered for monitoring climate change effects, although changes in land use require much shorter intervals. Long term monitoring of permanent sites should not only considering soil OC, but also all other surrogated soil properties so to allow the understanding of OC dynamics and its influence on other relevant soil functions.

To face the challenges associated to climate change impacts in the soil resources, we need tools allowing to detect changes and to make projections and scenarios in order to develop decission suport systems that may facilitate preventing impacts. Next we suggest selected measures following and completing the suggestions made by The European Strategy for Soil Protection:

– Basic soil information. This information is critical for the applications of predictive models for future scenarios

- Soil map at an appropritae scale, e.g.1:50,000
- Soil profiles data bases linked to the cartography. This will require collecting extant information which is scattered in different institutions.
- Historic temporal series. The collection of data bases may help to identify hitoric soil series that could be useful to characterise changes.

– Improving follow-up

- Existent permanent experimental sites should be maintained, especially those covering longer time periods.
- To identify new sites combining factors that are not sufficiently represented by the existent experimental sites.
- A more ambitious network of sites or plots should be considered for soil OC monitoring. Temporal and spatial scales for detecting changes should be further onsidered
- In areas susceptible to salinisation and sodiufication, the follow-up of the following parameters is recommended:
    - Electrical conductivity as an indicator of salinisation.
    - Sodium absorption ratio (SAR) as an indicator of sodium enrichment.

- Soil erosion monitoring. Given the difficulty and high economic cost of soil erosion monitoring, the proposed approach is base on indicators and modelling.
  - Cartography of the observable evidences of soil erosion in order to produce risk categories by area.
  - Continued measurements of sediment transport in the microcatchment gauging.
  - Measurements of sediment deposition in reservoirs, ponds and lakes. Considering that soil erosion is very variable in time and in space, erosion measurements should be continuous. Long term measurements, for example 10-year periods, can be used to obtain mean values.
  - The area subjected to erosion risk is proposed as an indicator of soil erosion.
  - Callibrating and validating require measurements of the real erosion rates in the field. It is recommended that first utilise the existing experimental stations, and only to raise the number of stations in places where there are insufficient data.
  - Selection of experimental stations (plots and catchments): the areas selected should present a moderate or high risk of erosion and be representative of an agro-ecological zone.
  - Interpolation of results from local measurements to large areas, in order to evaluate the state of soil erosion in areas for which no data are available, while the local factors affecting soil erosion are analysed in detail.
  - Analyses of scenarios aimed at predicting soil erosion under conditions of different land uses and/or of climatic change.

8.9. IMPLICATIONS FOR POLICIES

The soil phsically supports most of human activities. Therefore, it is unavoidable the confrontation of various interests and uses on the soil resources. Dealing with this complexity is not an easy task, however new approches are progressing on the basic recognition of the necessity of integrating environmental elements in the land use policies, in the framework of a sustainable development. This is refelected in the elaboration of The European Strategy for Soil Conservation that would provide the basis for the development of European regulations on soil conservation and sustainable use of soil resources.

According to the preparatory documents for the European Strategy, land planning is a key instrument for soil conservation. The last report emphasises that soil quality should be considered in any development plans or reclassification of land uses. At present, a large amount of our best quality soils are disappearing as a result of sealing (construction) in periurban areas of the big conurbations.

The Common Agricultural Policy (CAP), through agro-ecological measures, promotes sustainable management practices applied to agricultural soils. In the recent past, it has also promoted the abandonment of marginal croplands and the reforestation of these (Reg. 2080/92 and 1257/1999), with an environmental objective in mind (complementary to the primary objective involving the maintenance of profitability in the agriculture sector). The CAP reform offers possibilities to improve the conservation of soils and to increase carbon fixation.

The Spanish Forestry Plan and those of the regional autonomies are incorporating carbon sequestration into their objectives.

8.10. MAIN RESEARCH NEEDS

In Spain, there has been no generalised and continuous activity of soils description and characterisation. This lack of basic information on the geographic variability of soils is particularly evident in any attempt to specify the impacts of climate change. Long-term basic studies should therefore be promoted in order to attempt to detect the evolution tendencies of soils and the responses of these to disturbances and climate change, especially in relation to low-periodicity events. An initial basic need with regard to soil resources is the inventory of soils at an useful management scale (at least 1:50,000), with which to establish an evaluation of their condition, plan management and project change tendencies.

New studies for the survey, evaluation and monitoring of soils would place particular emphasis on selected indicators of soil quality, such as hydric properties (for example, S-theory, Dexter 2004).

With regard to the effects of climate change on soil OC, studies are needed to jointly analyse the effects of increases in atmospheric CO_2 and changes in temperature and rainfall. In relation to mitigation measures, research should be reinforced in the use of organic amendments and the impact of their quality, combined with other soil management techniques, to increase soil OC sequestration, considering the implications and role of soil biological activity and diversity.

Research is needed into computerised systems aimed at facilitating the transfer of information and knowledge of soil resources to politicians and direct users of the territory, both for present scenarios and for those of climate change. Support decision systems in the planning of land uses, along with the formulation of management practices adjusted to each soil type (for example MicroLEIS DSS, de la Rosa *et al*. 2004), are now a reality, and offer extraordinary possibilities for application and adaptation.

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9. IMPACTS ON THE FORESTRY SECTOR

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ABSTRACT

In Spain, forests take up around 15 million hectares, to which must be added 11.5 million hectares of different types of shrublands and pastures on forest land. This forest area as a whole produces 1,200 million Euros per year (without considering livestock farming production) of which timber represents around 800 million. Society receives other goods and services from the forest, which, at present, are difficult to quantify economically, but are, however, very important. Among these we can highlight protection against erosion, control and regulation of the hydrological cycle, the contribution to conserving biodiversity and the recreational use.

Some species of pines or oaks originated millions of years ago and have survived several climatic fluctuations. Adult trees are capable of resisting a certain degree of environmental stress, but the forest is more sensitive during the regeneration phase. Together with climate change, environment retreat increases the sensitivity of the species, as many forests cannot now reoccupy previous territories, due, for example, to problems of erosion resulting from a lack of plant cover.

Forest pests and diseases can play a fundamental role in the fragmentation of forest areas. Some perforating or defoliating species can complete up to two biological cycles per year or increase their colonisation area as a consequence of more benign winters.

The physiology of most forest species could be profoundly affected. The vegetative period of deciduous trees is lengthened. The renovation of leaves and thin roots in evergreens is accelerated, altering the plant’s internal carbon balance. The greater carbon consumption the tree needs to invest in order to renew these structures increases the consumption of reserve carbohydrates, thus making forest ecosystems more vulnerable. There is a high risk that many of our forest ecosystems will become net carbon emitters during the second half of this century. Culminal mountain areas, the more xeric environments and riparian forests could become more vulnerable to climate change.

In view of the foreseeable changes, an adaptational strategy is recommendable. Resalveo of the underbrush to reduce pies density has proved to be an efficient treatment that improves the response of these forests to climate change. Control and adjustment of exploitation turns and intensities should be considered as an option for optimising the response of the forest. Equally important is the careful selection of the origins of the seeds in reforestation, for appropriate management of genetic diversity.

Among the most pressing needs for the future, we can highlight the need for more accurate knowledge of the subterranean biomass of our forest species, given the primordial role played by the underground fraction in the response by the forests to disturbances, necessary for establishing the values of the carbon accumulated in our forests, and also to establish or consolidate networks for the observation and analysis of the ecophysiological factors determining regeneration and, as a whole, the response of the forest to environmental changes; another aim involves promoting the development and application of forest growth models, especially those based on physiological processes, aimed at predicting the response by the forest to environmental changes or management patterns.

9.1. INTRODUCTION

Forests constitute one of the most complex natural landscape units with regard to function, structure and dynamics. Since time immemorial, man has made use of the different products and services that forests have provided him with: timber, firewood, fruits, resins, fungi, shelter and protection, recreation, etc. This diversity of products constitutes the best indicator of the complexity involved therein.

In past times, forests were used according to the needs of the neighbouring populations and communities, regardless of the production capacity. There was no concept of sustainable forestry production, which appeared in the first half of the XIX century, with the generalised application of Forest Planning and the first basic forestry techniques.

At present, the maintenance, care and improvement of forests is not governed by simple production criteria, however important these may be, it being fundamental to consider the need of different countries to avail of abundant and well-distributed forest areas as a basis for biological and social balance. In industrialised societies, such as ours, there is a deep-rooted concept of the multifunctional forest, a generated structure of biological diversity and a source of multiple products, services and uses – a multiple-use function of our forests. In this sense, the forest and sylvo-pastoral systems of the Mediterranean environment constitute a clear example of sustainable management of multifunctional forests.

The scope and importance of the Forestry Sector in Spain is reflected in the area occupied by forests in our country, in the characterisation and quantification of the products and services provided to society by these lands; and, for those products for which sufficient information is available, in the description of the industrial sectors associated with this sector.

9.1.1. Spain's Forest Area

Forest Law 43/2003, dated November 21st 2003 defines forest area in the first section as "*...all land on which forest species of trees, bushes, shrubs or herbaceous species grow, whether this be spontaneously or through sowing or planting, which fulfil or can fulfil functions related to the environment, protection, production, culture, landscape or recreation...*" . Making use of this definition, Spain's Forestry Plan estimates the national forest area at 26,273,235 ha, which is 51.4% of the country's area. This area can be classified according to the type of plant cover it sustains (table 9.1):

Table 9.1. *Distribution of Spain's forest area according to cover.*

Type of cover	Area (ha)	Type of species	Area (ha)
dense forest (FPC>5%)	14.732.247	Conifers	5.833.970
		Broadleaved	4.287.084
		Mixed	4.581.729
open woodlands (FPC<5%)	9.228.407		
grasslands	2.312.581		

FPC=Foliage Projective Cover

The ownership of this forest land corresponds to the State, the Regional Autonomies, local organisms and private individuals, in the proportion presented in the following pie chart:

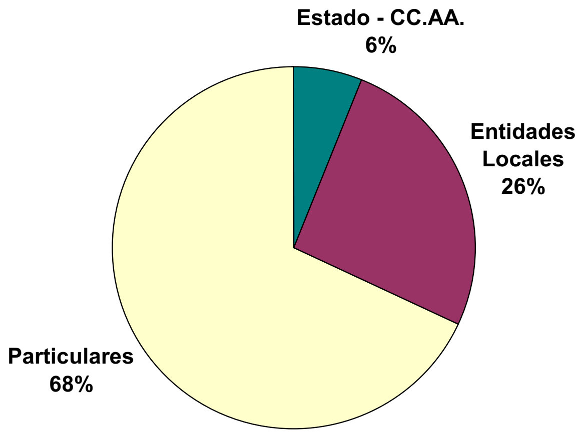

Fig. 9.1. *Ownership of forests in Spain (State-Regional Autonomies; Local institutions; Private owners)*

9.1.2. Forestry production: Quantification and Valuation

The lack of an exclusive source of forest statistics and the non-existence of central markets of forestry products hinder the quantification and valuation of products of commercial interest. It is also necessary to include in forestry production a series of goods and services that forest ecosystems provide to society, the valuation and quantification of which must be developed through indirect methods (surveys, contingency valuation, etc.). These conditions will hinder the valuation and quantification of forestry production in general.

9.1.2.1. Products of commercial interest

The use of forestry products, in accordance with Forest Law, corresponds to the forest owners. The regulation thereof is, however, the responsibility of the pertinent forestry administration, which constitutes a guarantee for the persistence and sustainability of the forests and the associated production. Table 9.2 shows the annual quantification and valuation of the different forestry products, valued once extracted from the forest but not industrially transformed. Total non-transformed forestry production totals 1,200 million Euros annually (without considering livestock farming production). This figure means that annual average revenues from forestry (considering only products of commercial interest) could total 45.67 €/ha.

9.1.2.2. Timber production

The main production of commercial interest obtained from forests is timber, the value of which is estimated at 800 million Euros per year. In Spain, annual extraction of timber totals 18,000,000 m^3. A global indicator of the sustainability of timber production is the comparison between production and the annual growth of the exploitable stocks accumulated in our forests. According to the Spanish Forestry Plan (SFP) spanish forests accumulate 675,000,000 m^3 of timber, with an annual growth rate of around 35,500,000 m^3. This means that only 50% of annual growth is extracted from the forests, which guarantees compatibility between the persistence and spread of forest cover and the timber industry.

Table 9.2. *Valuation and quantification of forestry products of commercial interest*

Product	**Category**	**Production (10^3 tm/year)**	**Valuation (10^6 €/year)**
Timber	Conifers	9082 *	396
	Broadleafs	5696 *	253
	Unclassified	3289 *	143
Firewood	Gross firewood	1250	40
	Fine firewood	2000	
Cork		85	90
Resin		4.2	2.5
Fruits	Acorns	400	19
	Chestnuts	20	13
	Pine kernels wit shell	6	18
Fungi		9	30
Medicinal plants		3	0.03
Game		1326000 +	155
Continental fisheries		834680+	25
Honey		0.02	0.06
Logging	Sand	1500	0.38
	Gravel	1750	3
	Stone	3000	1.6
Livestock		140000**	
Others			9
TOTAL TIMBER			800
TOTAL NON-TIMBER PRODUCTS			400
TOTAL FORESTRY PRODUCTS			1200

* 10^3 m^3 with bark ; + licences issued; ** tons in fresh weigth, not valued economically. *Fuente Anuario de Estadística Agraria* (AEA) (annual agriculture statistics source).

The apparent consumption of timber in Spain (extraction + import – export) is estimated at 32,500,000 de m^3. The deficit between production and consumption is currently covered by imports, both of lumber and of transformed products (pulp, paper, sawn timber, furniture...). Average timber consumption per inhabitant and year in Spain is 0,8 m^3. The fact that this figure is lower than that of the neighbouring countries, together with the consistent growing tendency in recent years, indicates that in the coming years there will be an increase in apparent timber consumption in our country, which will need to be covered either through an increase in national production or through imports.

9.1.2.3. Other goods and services produced in forests

Carbon sequestration

Forests act as elements that uptake CO_2, the main gas that contributes to the greenhouse effect and to the global warming of the planet. CO_2 sequestration in forests and in derived forestry products constitute a fundamental element of the carbon cycle. In the year 2004, Spanish forests (considering only forest lands) accumulate a total of 2,050 million tons of CO_2, with an annual net increase in sequestration equivalent to 40 million tons (Montero *et al*. 2002, 2004). This figure is equivalent to approximately 10% of the total CO_2 released into the atmosphere in Spain in 2002 (Anonymous 2004).

Protection against erosion and control of the hydric cycle

Hydric erosion is the main agent of desertification in Spain. In Spain, about 18.2% of the territory has erosion losses greater than 50 tm/ha /year (Anonymous 2000). Hydric erosion causes the loss of fertile soils in areas in which these are necessary for the maintenance of the biological potential of the territory, and the subsequent accumulation of these materials in other areas, with consequences that are often catastrophic (floodings...). Of all the possible types of cover in the territory, forests are the most efficient protectors, favouring the regulation of water quality, preventing floods and prolonging the life of reservoirs.

Conservation of biodiversity. Protected natural areas

In Spain, over 12 and a half million hectares of land have been included in the Red Natura 2000 network, either as *sites of community importance* or *Areas of special protection for birds.* In these territories, the regulations oblige the necessary measures and mechanisms to be included in the management process in order to guarantee the conservation of biodiversity. Over 70% of the territory included in the Red Natura (around 9 million hectares) are classified as forest land, which indicates that forests constitute the most important element of the territory with regard to the conservation of biodiversity. The non-use environmental assets (protection and conservation of biodiversity) are valued in 1,220 million Euros per year (Anonymous 2003).

Recreational use and landscape

Forests are a basic element of the landscape, and an area for leisure and expansion of the population. The management system of Spain's forests includes the controlled and rational enjoyment thereof, compatible with traditional uses. One of the basic tools for reaching this objective was the creation and maintenance of concentration zones (recreational areas, camp sites and refuges) and information centres and nature schools, facilities that help the citizens to approach and understand nature, and to become integrated into the forest environment. The recreational and landscape use of the forest was valued, with the use of contingency valuation methods, at 640 million Euros per year (Anonymous 2003).

9.1.3. Economic valuation of the different products and services obtained from forests

Table 9.3 presents the total annual value and per hectare assigned to the different products and services obtained from forest lands. These figures are an underestimation, as livestock farming production was not considered, and only the value of the net carbon uptaked annually by forests (without considering that uptaked in non forested lands, or assigning a value to the carbon accumulated.

Table 9.3. *Valuation of services and products.*

Service or product	Annual value (10^6 €)	Annual value (€/ha)
Timber	800	30.45
Non-timber forestry products	400	15.22
Annual net Carbon sequestration	220	8.37
Environmental assets (protection, conservation)	1220	46.45
Recreational use and landscape	640	24.36
TOTAL	**3280**	**124.85**

* (only forest lands, using as a reference value 5.5 €/t CO_2)

9.1.4. Public investment in the forestry sector

Public investment in the forestry sector was 20% of total public investment in the environment, reaching a value of over 820 million Euros in 2002 (ASEMFO 2002). Public investment in the forestry sector is mainly implemented by the regional Autonomy Administrations (580 million €) and Central Administration (240 million €). The regional administrations finance both actions on forested land, the management of which they control (normally publicly owned) and grants for intervention in privately owned forests. Investments by the Central Administration of the State focus both on the maintenance of integrated services (protection against forest fires and toxic agents, Nature Database), the management of National Parks and co-funded actions with the Regional Autonomies (FEOGA, complementary measures by the CAP).

Considering Spain's Forest Area, the average investment per hectare and year, financed through public funds, is estimated at 31.53 €.

Table 9.4. S*ummary Forestation Programme on Agricultural Land (1994-1999)(Anonymous 2003)*

AID FOR FORESTRY	
Dossiers opened after implementation of work	34 981
Subsidisable area	451120 ha
Total cost (FEOGA+State)	608 10^6 €
Average area per beneficiary	12.9 ha
Average cost forestation	1348 €/ha
FORESTED AREAS MAINTENANCE SUBSIDIES	
Number of beneficiaries with application accepted	34 697
Subsidisable area	439923 ha
Total Subsidisable cost	421 10^6 €

The main investment in forestry in Spain in recent years has involved the Forestry Programme on Agricultural Land, implemented as a measure accompanying the CAP, within the framework of community regulation 2080/92. This action, mainly financed by community funds, involved an average investment between 1994 and 1999, of over 200 million Euros. The main result of this plan was an increase by 450,000 ha in national forest area. Table 9.4 summarises the results of the programme for the period 1994-1999.

9.1.5. Production-investment balance in forests

Considering the annual valuation of the products, goods and services produced by one hectare of Spanish forest land in one year, estimated at 124.85 €, and the assigned public investments, estimated at 31.53 € / hectare/year, we obtain a clearly positive balance, of over 90 € / hectare/year. Considering that this valuation did not include forest livestock production, or valuation of accumulated carbon (only the net carbon uptaked each year was considered), and in view of the result obtained, we can conclude that the maintenance, management and sustainable use of forests is clearly a positive activity for society.

9.2. SENSITIVITY TO PRESENT CLIMATE

For the main forest species, those defining landscape and complementing rural economies, Climate Change is not a recent phenomenon. Some species of *Pinus* or *Quercus* originated millions of years ago, and have therefore survived climate fluctuations. Due to their longevity, the change occurs in their cycles, which is why they have necessarily survived the extreme values of the last few centuries. Phyto-geographycal studies show how lineages located in glacial refuges on the Iberian Peninsula had sufficient genetic variation to adapt to the change. Under conditions of warming in the Holocene, forest species rose up the mountainside or were displaced northwards as the glacial ice caps retreated. This is the case of white oaks, one of the best studied groups in Europe (Petit *et al.* 2002).

Adult trees are capable of resisting intense environmental stress, but they are more sensitive when the forest is being regenerated. This requires continuous success in several successive ecological processes, from pollination to the establishment of seedlings. Many of these processes are quite unknown in forest species, which must be situated in a disturbance regime that creates differential opportunities for the co-existence of several tree species, a generalised situation in our country.

Climate Change is not the only factor forest species are faced with. Sensitivity to present climate is greater due to environment retreat. Many forests are unable to recover lost areas. The effect of degradation is more intense in territories with abrupt topography, with a profile of rejuvenated soils and with erosion problems resulting from the lack of plant cover, or in climates unfavourable for regeneration due to the lack of rainfall. Among other processes, we can highlight the overexploitation of aquifers, which has eliminated the water table close to the surface and brought numerous populations close to extinction, including cork oak, Holm oak or gall oak forests, affected by drought, and unique forest, such as the population of *Pinus sylvestris* in Coca (Segovia), located among the *Pinus pinaster* forests thanks to the presence in the past of an accessible water table. The severe reduction of this population has severely affected the reproductive system of an anemophilous and alogamous species (Robledo Arnuncio *et al* 2004). The latest regenerative event of the population occurred almost one century ago, and a population adapted to the temperature characteristics of the Northern Plateau, more severe than on the slopes of the Guadarrama mountains, is on the verge of disappearing.

The capacity to adapt to environmental changes is associated, in the short term, with greater phenotypical plasticity; this is higher in species of over five hundred years of life span (*Pinus nigra, P. canariensis, P. sylvestris, Quercus ilex* or *Q. petraea*) and with vast distribution ranges. Population variability is high therein, as the genetic flow prevents disruptive selection and speciation. Natural selection is quite inefficient because the environment is heterogeneous and the variation component within the populations is much greater than that existing between populations. In species with a higher evolutionary level, such as oaks and Holm oaks, we can expect greater intrapopulation genetic diversity, especially if they are indifferent to edaphic factors, because they resist greater environmental heterogeneity in space and time. In heliophilous species, like pines, variability is lower, because they colonise empty spaces and only acquire permanence on rustic land, where the poor soil prevents Holm oaks and oaks from successfully rooting, and conifers therefore have an advantage over them due to their higher growth rate.

In the short term, the sensitivity of forest species will depend on their capacity for dispersal and on the genetic variability at the heart of their populations. Man has eliminated them or fragmented their distribution area or has degraded their habitat. The time of response has been shortened, because the most suitable land is destined for agriculture and there is much more land suitable for pioneer species. In dry, open and contrasted habitats, extreme climate values are harsher, and species disseminated by the wind are more easily dispersed. Frequently fruiting species facilitate coincidence with favourable years for regeneration, but greater longevity allows for the appearance of favourable events in species which concentrates regeneration events in particular years.

As with other causes, sensitivity to present climate is related to the demography of the populations and with recent reproduction events of sexual origin that have been subjected to the selective pressure of the environment. Certain processes favour genetic diversity, in the characters affected by climate change, such as leaf overheating, to which pines are less vulnerable than broadleaf species, due to the presence of needles and a more efficient cooling system. It is assumed that when more than one species appears in a place, this is due to spatial diversity and to the temporal fluctuation of climatic variables. This situation favours the occupation of existing niches by populations with high plasticity and interspecific diversity. Competition in the ecotone between strains of different ecological significance is responsible for higher diversity values, when compared with those of more homogeneous territories.

Another positive aspect to consider, which characterises the last half century, is reforestation and the abandonment of traditional agro-pastoral practices, which are extensive and marginal. Forests have recovered vast areas, which allows the species to show much of their potential for adaptation, because the demographic increase in individuals.

9.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

9.3.1. Forest pests and diseases

The foreseeable impact of Climate Change has a particular effect on forest ecosystems, both directly and through the different elements that comprise this universe, and among these, pests and diseases could play a relative role in the fragmentation of forest areas, along with the process by which species become rarer and the simplification of the biodiversity inherent to these spaces, leading, in extreme cases, to the disappearance of the vegetation. Change, simplification and risk of disappearance are foreseeable consequences in the short and medium term.

Pests and diseases are inherent to forest ecosystems. As another element of the trophic network, they contribute, in an endemic or epidemic manner, to the rejuvenation and dynamics of the existing vegetation. They are occasionally a key element in the succession of plant formations and a good indicator of climatic variability: The poikilothermia inherent to most arthropods makes them adjusted bioindicators of climate and variations thereof. The importance of pests and diseases in a scenario of CC should therefore be considered from two radically different perspectives:

- Their presence or absence as early warning indicators of climatic variations in the environment.
- The impact associated with the damage they cause, an element that accelerates the rupture of the plant-system balance and which often camouflages other agents that initiate this imbalance (in this case, climatic variation).

Increased temperatures and the consequent lengthening of the optimum periods for the development of pests and diseases can have a greater and more long lasting impact on the vegetation upon which they feed. The conifer perforators *Ips acuminatus* and *Ips sexdentatus* can complete up to more than two generations in one year, if the movement of imagoes can be advanced by one month as a result of the temperature increase, and can be prolonged throughout the autumn. Defoliators such as *Diprion pini* can habitually develop two cycles, or the pine caterpillar can increase the area susceptible to colonisation, on being able to rise in altitude in warmer winters, and colonise in a natural way of *Pinus silvestris* forests which have heretofore escaped impact.

In all these cases, the insects are only mere indicators of climate conditions, and the impact they have only serves to camouflage the role played by these precursor agents. Along with this, the capacity of the plants subjected to hydric and thermal stress to resist the attack, is undermined.

But the greatest threat is undoubtedly posed by the pests and diseases exogenous to the environment, the so-called *alien species* or quarantine organisms. The combination of these species, the undesired result of international trade, host species lacking mechanisms for adaptation or for mitigating the impact, and optimum climatology for the development of the pathogen, lead to exponential damage being caused, against which the vegetation has practically no defence. The development of *Lymantria dispar* in North America, the presence of scolitid fauna and other aloctonous perforators in any forest system, or the development of syndromes such as *dieback* in the Southwest of Europe or *Sudden oak death* in North America, with interaction among fungi such as *Phythopthora*, *Bothryosphaeria*, bacteria such as *Brennia*, scolitids and the impact of continuous hydric deficit and heat waves that prevent recovery of the soil's hydric reserves, presents a panorama which, at best will involve the substitution of some forest species by others, better adapted to the new conditions, or at worst, the progressive fragmentation and disappearance of certain forest species. The worrying situation of *Abies alba* in some parts of the Pyrenees or of *Quercus suber* in the Southwest of the Iberian Peninsula, could be an indicator of this complex process.

9.3.2. The average life of evergreens will be shortened in the future

Leaf renovation, which can be represented by the average life of the leaf, is very much associated with temperature. It has been observed, in the case of evergreen trees, like the Holm oak or the pine, that a temperature increase can accelerate their leaf dynamics, reducing the duration of the leaves on the crowns, which accelerates even more in the case of drought conditions. The average life of Holm oak leaves is 2.8 years in Montseny (north-east Spain), where mean temperature is 10º C, with 700 mm annual rainfall, and 1.7 years in Seville (south Spain), where mean annual temperature is18.8º C with 535 mm annual rainfall (Gracia *et al*. 2001). These observations are also valid for fine roots which last on average little more than 100 days in the Prades Holm oak forest and which disappear in conditions of drought (López *et al*. 1997, 1998, 2000, 2001a, 2001b). Leaves and fine roots therefore require important amounts of mobile carbon for renovation. If climate change causes temperature increases, we deduce that the renovation of leaves and fine roots will accelerate. Furthermore, in the case of deciduous trees, (such as beeches and oaks), the duration of the leaves will increase: they advance sprouting time and retard the moment when the leaves are shed, which is seen in a longer growing season and therefore a longer production period. Although if these species are faced with more accentuated summer drought periods due to climate change, things may go badly for them (McClaugherty *et al*. 1982, 1984). It must be kept in mind that the leaves of deciduous trees are generally less sclerophyllous and more sensitive to water loss than those of a hard-leafed evergreen like the Holm oak and that they might therefore have less resistance to water loss during a prolonged episode of hydric stress.

The impact of climate change upon leaf duration and the derived physiological effects were evaluated on 147 plots of evergreen species from the Catalonia Ecology and Forest Inventory (Gracia *et al*. 1992, 2000). The mean value of the variable for the 147 plots analysed was 2.6 years, most of the values being between 2 and 3 years and only in some sites, all of these in mountains of the Pyrenees, Puertos de Beceite or Montseny, with values of over three years. In the year 2040, the predicted distribution in the results of the simulations changes notably, with a resulting mean value of 1.9 years, which represents a reduction of 27% of the leaf life span. This reduction of leaf life is reflected in an increase in litterfall production, which varies from 205 g of C $m^{-2}\cdot year^{-1}$ at present to values of 377 g of C $m^{-2}\cdot year^{-1}$ in the year 2040. This increase by almost 80% in the organic matter reaching the ground affects respiration rates. By total respiration, understanding here the sum of the autotrophic respiration of the trees (maintenance respiration plus growth respiration invested in the formation of new tree tissue) plus the heterotrophic respiration coming mainly from the decomposition of soil organic matter. The amount of carbon returned into the atmosphere annually by forests in Catalonia is, on average 1462 g of C $m^{-2}\cdot year^{-1}$ and this value increases to 2307 g of C $m^{-2}\cdot year^{-1}$ in the year 2040, which is an increase of 70% in relation to present values.

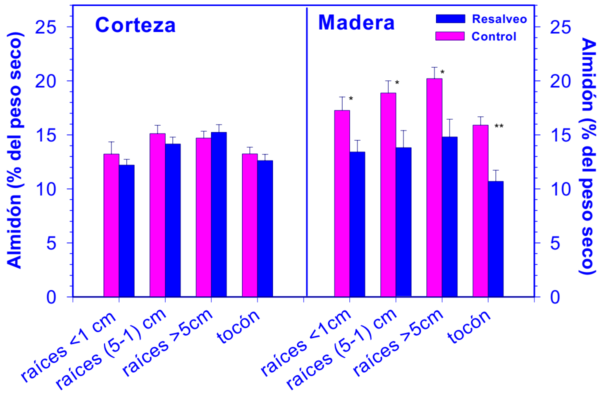

***Fig. 9.2.** Percentage of starch in different fractions of the root system of the Holm oaks in control and thinned plots, measured one year after thinning. The percentage of starch in the wood of the thinned plots is five per cent less than the control plots. The difference is due to the starch mobilised following the treatments. In absolute terms, this percentage represents around 10 tons of carbon which is mobilised after thinning. This result shows the importance of mobile carbon reserves in trees.*

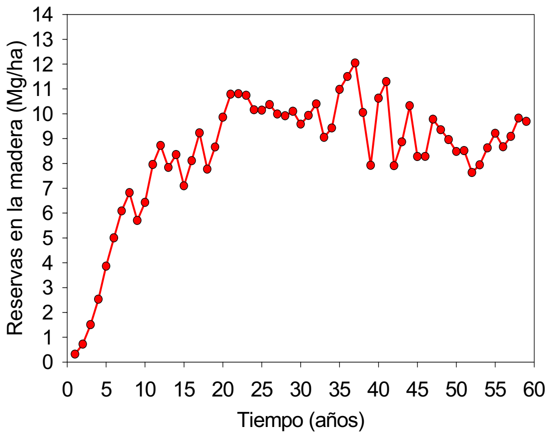

***Fig. 9.3.** The mobilisation of starch after thinning or a fire or any other disturbance must be compensated for by the carbon fixed by photosynthesis. When large amounts are mobilised, like in the aforementioned thinning experiment, the tree may take a considerable amount of time to replace the reserve. During all this time, the plant may be sensitive to other disturbances that it cannot resist due to the lack of reserves of mobile carbon. The recovery of the ten tons mobilised after thinning requires an approximate time of 20 to 25 years, as shown in the graph.*

9.3.3. The greater consumption of mobile carbohydrates with increase the vulnerability of forest ecosystems

New shoots are formed through the mobilisation of considerable amounts of reserve carbohydrates stored in the subterranean structures (Breda *et al*. 1995). Starch represents over 95% of reserve carbon. Figure 9.2 shows the starch content in the bark and wood of the subterranean structures.

Starch represents around 15% of the biomass in the stump and the roots and does not undergo any significant changes after thinning (Gracia *et al*. 1994, 1996, 1999a). In the woody tissues, starch represents between 15 and 20 per cent of belowground biomass, which is equivalent to 21.2 Mg/ha. Of this amount accumulated in belowground biomass one year after thinning, in the treatment referred to in figure 9.2, 6.1 Mg/ha had been mobilised, which is around 30% of the reserves accumulated by the roots.

In the mobilisation of this considerable amount of reserve carbon lies the capacity of the Holm oak to regenerate the structures that have been altered by a disturbance. This consumption of reserves, however, leaves the tree in a temporary state of precariousness, on preventing it from dealing with disturbances that occur too frequently. It is therefor pertinent to establish the time needed by the plant to bring reserves back to the levels existing previous to thinning. Figure 9.3 shows the evolution of the reserve starch in the wood of the subterranean biomass. These results show that the time needed to accumulate the 6.1 Mg/ha mobilised after thinning is around 20 years. This result coincides with the time that traditionally elapses between the two successive cuttings to produce charcoal in the traditional use of these Holm oak forests, which would justify, in terms of the tree's physiology, a certain empirical optimisation of the traditional use of these forests. The increased summer drought in Mediterranean environments predicted by the climate change models will contribute to increasing the consumption of reserve carbohydrates, thus increasing the vulnerability of many forest species to adverse episodes (Aussenac and Granier 1988, Ball *et al.* 1987, Brix and Mitchell 1986, Jarvis 1998).

9.3.4. The hydric reserve of forest soils will be reduced, hindering recovery after episodes of summer drought

The water content in the soil of a forest varies greatly, from values close to zero during summer drought to maximum values during periods of more or less abundant and continuous rainfall. According to the analyses conducted in the aforementioned 147 forest plots, the hydric reserve in the soils of Catalonia's forests (averaged throughout the year) is 32 mm. The temperature increase and the greater evaporation demand of the atmosphere around 2040 will reduce this annual mean value of the reserve to 24 mm, which represents a decrease of 25% of the present water content in forest soils (Gracia *et al*. 2001, 2002).

In those sites in which the forest avails of sufficient water to compensate for the greater hydric demand associated with the temperature increase and potential evapotranspiration, an increase in forest production can be predicted. Although, in places with a hydric deficit, which represent many of Spain's forest ecosystems, we can expect big changes, ranging from reduced tree density to changes in species distribution. In extreme cases, areas currently occupied by forests could be substituted by shrubland, and areas currently occupied by shrubland might be exposed to the impact of intense erosion.

This is why it is important to anticipate the changes we are exposed to and the possible role of adaptive management aimed at redirecting or, channelling, or at least optimising the response by our forests to climate change.

9.3.5. Our forests will become net emitters of carbon in the second half of this century

The maps in figure 9.4, which show the net production of European forest ecosystems, and the maps in figures 9.5 and 9.6, referring to the Iberian Peninsula, represent an attempt to explore the effects of climate change on some variables considered to be particularly sensitive, with the use of the model GOTILWA+ (Gracia *et al.* 1997, 1999b, 2001, Kramer *et al.* 2002, Mohren 1999, Mohren et al. 1997, 2000). These were obtained with the use of a 10 x 10 minute pixel. The climate of each pixel corresponds to that estimated by HadCM3 model, using socioeconomic scenario A2 (Carter *et al.* 2000, IPCC 2001 Watson 2001). The results of figure 9.5 represent the net production of the ecosystem in European forests in the years 1990 2020 2050 and 2080.

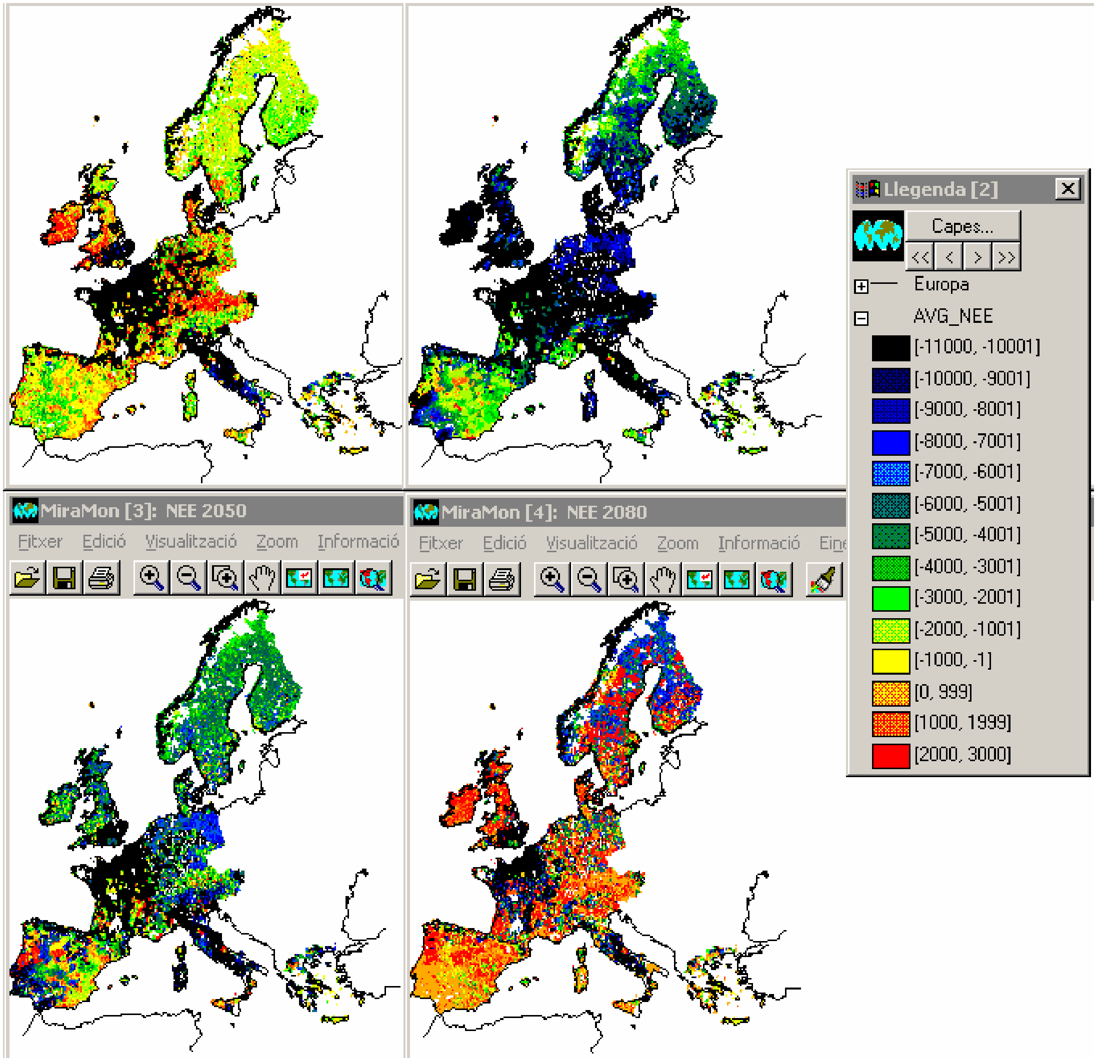

Fig. 9.4. *Estimation of net Production of the ecosystem in European forests. The maps show the situation in the years 1990 2020 2050 and 2080. In the ATEAM project, GOTILWA+ model is being used to simulate the growth of European forests under the different scocioeconomic scenarios of climate change defined by the IPCC. The maps of the figure were obtained using a 10 minutes x 10 minutes pixel. The climate of each pixel corresponds to that estimated by the HadCM3 model using socioeconomic scenario A2 (IPCC 2001). The results show that on the Iberian Peninsula, the sink effect of forests can undergo a transitory increase for a few decades, but towards the second half of the present century, forests will invert their role as sinks and become net emitters of carbon into the atmosphere.*

The results are eloquent and generally coincide with the patterns predicted by other models (Aubinet *et al.* 1998, Ceulemans and Mousseau 1994, Epron and Dreyer 1993a, 1993b, Medlyn and Dewar 1996, Medlyn and Jarvis 1997). In spite of the fact that on the Iberian Peninsula, the sink effect of forests may undergo a transitory increase for a few decades, in the second half of this century, they will invert the role they play as sinks and become net emitters of carbon into the atmosphere. With regard to water reserves in the soil, the results of figure 9.6 show that on the Iberian Peninsula, the groundwater reserves progressively diminish in the summer months. The lack of water in the soil in summer constitutes a serious risk for the survival of some forests.

9.4. MOST VULNERABLE AREAS

Populations whose southern limit is located in the high parts of mountain ranges will be the most affected, in particular if they coexist with more thermophilic species or if they have little genetic variability. In general, the so-called restricted area origin, recorded by Martín *et al* (1998), due both to being outside the main distribution area and to problems of genetic derivation, to their susceptibility to natural disturbance or to human intervention, are more vulnerable. These dangers will be determinant if they are associated with changes in rainfall regime.

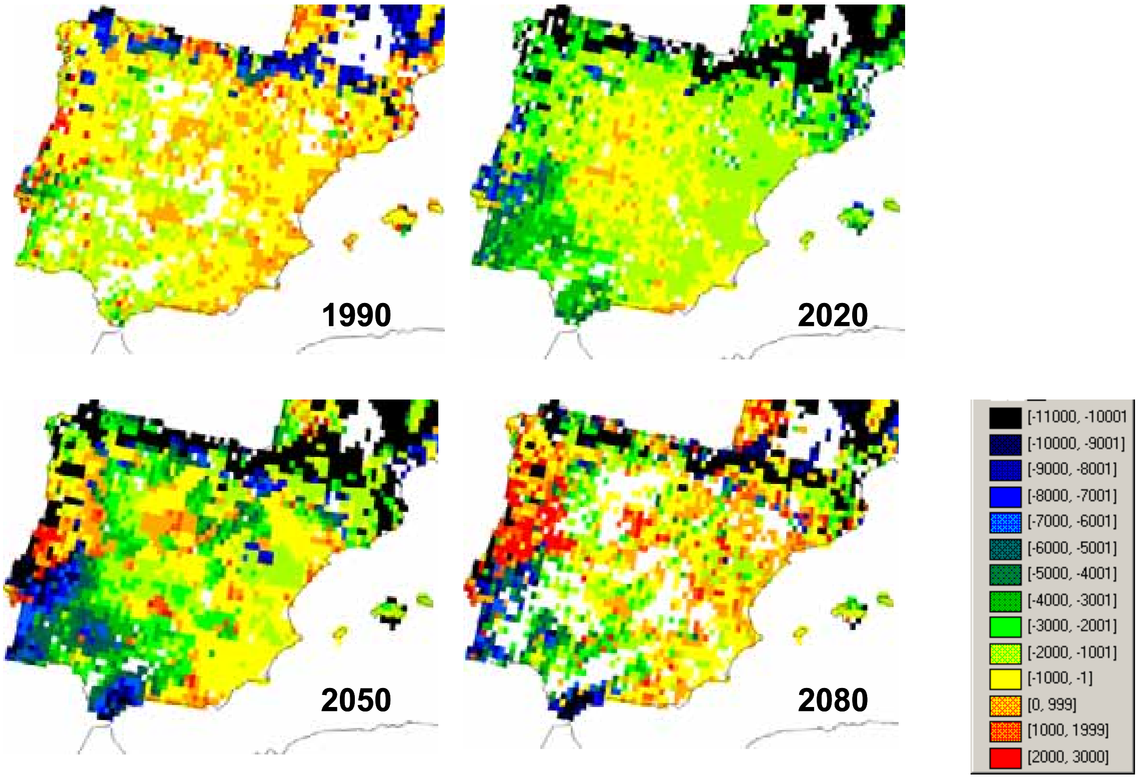

Fig. 9.5. *Estimation of net Production of the ecosystem in forests on the Iberian Peninsula. The maps show the situation in the years 1990 2020 2050 and 2080. In the ATEAM project, GOTILWA+ model is being used to simulate the growth of European forests under the different scocioeconomic scenarios of climate change defined by the IPCC. The maps of the figure were obtained using a 10 minute x 10 minute pixel. The climate of each pixel corresponds to that estimated by the HadCM3 model using socioeconomic scenario A2 (IPCC 2001). See figure 9.11.*

On the Iberian Peninsula, the forest area, not necessarily with trees, appears as a continuum crossing all the mountain ranges, generally interconnected by corridors. There is an acceptable change of these acting in many situations as corridors for rustic species such as conifers of the genus *Pinus*. A temperature increase and irregular rainfall will reduce the frequency of situations favourable for the establishment and consolidation of trees. Less capacity to accumulate reserves is also associated with greater vulnerability to disturbance (fires, pests, diseases), as the trees cannot handle renovation processes.

Debilitation resulting from a lack of adjustment to the new climate conditions will provide greater trophic availability to pests and, which will do their job as indicators of the decomposition cycle of organic matter. If global warming is associated with increased aridity, a greater proliferation of insects is to be expected, due to the greater sensitivity of fungi and other micro-organisms to dry periods. The lack of vigour in the present plant populations over a large area will allow for noteworthy increases in pathogen populations. Disturbances will accelerate change in present populations, which will be renovated by new produced plants more adapted to the new situation, or will be substituted by other, more thermophilic species with a better resistance to aridity. This is the case of the substitution of *Pinus pinaster* by *Pinus halepensis* in the inland mountains of Valencia, or of the substitution of the cork oak or the gall oak by the Holm oak.

9.4.1. Mountain top areas

If the distribution area covers the top area of the mountain ranges, the forest having no natural limits – like in most of the eastern ranges or those in the South of the Peninsula, with the exception of Sierra Nevada – an altitudinal rise will not be possible following a temperature increase. The few spots of *Abies pinsapo* are threatened. Also affected will be the populations of *Pinus sylvestris* in the Sierra de Baza range, those of *Pinus nigra* in the Betic ranges or those of *Pinus uncinata* in the Sierra de Gúdar range. In all these cases, the populations indicated have few individuals and are therefore more sensitive to change and are endangered, in particular, in Andalucia, due to the low genetic variability, caused by problems related to genetic derivations associated with historic human intervention.

9.4.2. Xeric environments

Global warming associated with changes in rainfall regime could lead to the disappearance of trees in territories at their limits of adaptation to drought, giving way to formations of herbaceous species associated with sporadic rainfall. One example with economic effects, due to being one of the most typical non-timber products of Mediterranean forests, can be found in populations of *Pinus pinea* in the sanded soils of the Northern Plateau, but can be extended to other areas. This pine generates a large seed that is dispersed by animals, as opposed to other species with winged seeds. The interannual variation of pine kernel production in the province of Valladolid over 40 years shows a continuous decrease in the moving average of the last 20 years (figure 9.7.) This tendency is accentuated in pine forests with lower pine production, which become incapable of guaranteeing species reproduction (Gordo 2004). In spite of its adaptation to warmer areas with intense summer drought, the natural regeneration of the umbrella pine is compromised. Under the current climatic tendencies (figure 9.8), it will become increasingly difficult for a good harvest to coincide with favourable environmental conditions in successive years in order to permit the establishment of seedlings and the survival thereof in the early stages. A good harvest saturates the predators that act as dispersers, and has sufficient genetic variability to express a potential for adaptation capable of resisting the new conditions. Retreat in area will occur in spite of adaptation to very poor environments which require very open forest. This interpretation is based on the fact that it is a pine whose spherical crown is the result of adaptation to conditions of development in intense sunlight, with no lateral competition from other trees. This morphology is the result of the lack of vigour of the apical meristems of the trunk and the main branches, as this growth pattern allows the number of codominant axis to be maximised. Only branches of a certain thickness are capable of sustaining cones with a weight of 0.3 kg (Mutke *et al.* 2004).

The availability of records of production in a characteristical area of the species enabled us to establish the factors that determine the magnitude of the harvests; and establish a model that accounts for 75% of variation and shows tendencies towards a warmer, drier climate (Gordo 2004). The most determinant climatic variable with regard to the size of the harvests corresponds to the sum of rainfall from January to May (P5F, figure 9.8) of the year in which the female estrobilous were produced and pollinated. The follow-up, based on data from the Valladolid meteorological station, shows a tendency towards reduced rainfall in this period by 15 mm per decade. The decrease in related to the appearance of smaller harvests, which reduce the genetic base of the new produced plants exposed to higher summer temperatures. The species is vulnerable in the more arid parts of its current distribution, and will be associated with less extreme environmental conditions, such as areas with a water table that ensures a water supply that produces a consistent harvest size.

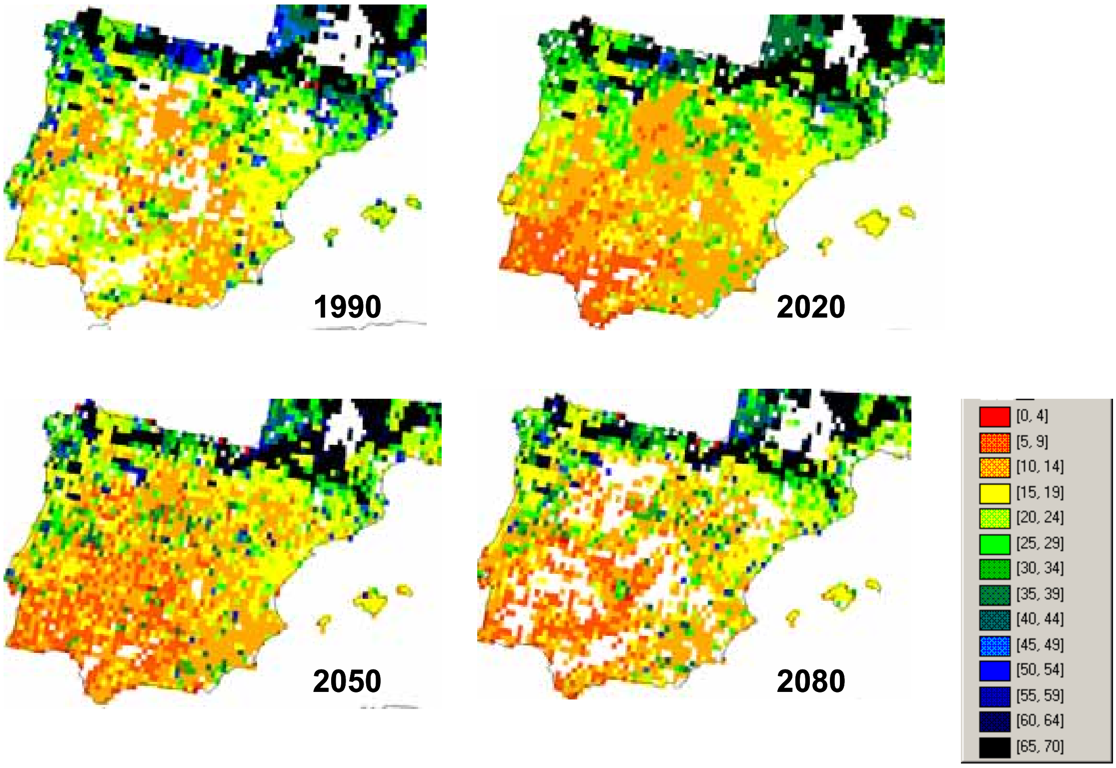

Fig. 9.6. *Estimate of average groundwater reserve in summer months in the forests of the Iberian Peninsula. The maps show the situation in the years 1990 2020 2050 and 2080. In the ATEAM project, GOTILWA+ model is being used to simulate the growth of European forests under the different scenarios of climate change defined by the IPCC. The maps of the figure were obtained using a 10 minutes x 10 minutes pixel. The climate of each pixel corresponds to that estimated by the HadCM3 model using socioeconomic scenario A2 (IPCC 2001). The results show that on the Iberian Peninsula, groundwater reserves progressively diminish. The lack of groundwater during summer constitutes a serious threat for the survival of some forests.*

9.4.3. Riparian forests

Riparian forests constitute one of the systems most affected by anthropic action, and have been drastically fragmented, with a reduction of their variability –as a result of man using the clonal capacity of their species as an exclusive form of reproduction- to the detriment of the sexual system. The construction of reservoirs, the regulation of river courses, the establishment of rockfills or the transformation of the riverbanks for crops or forests such as poplar groves, has fragmented the alignment of these forests and has reduced to a minimum their spontaneous manifestations, leading to the extinction of very unique ecological corridors. Forests of*Alnus* sp., *Populus* spp., *Fraxinus* spp., *Ulmus* spp. and *Tamarix* spp. are formations associated with the existence of a more or less permanent phreatic layer. An increase in mean temperatures will be linked with an increase in evaporation demand, which will require greater regularity of the phreatic layer. Changes in the rainfall regime will increase the torrentiality of our water courses, making them more irregular. A more spontaneous nature of the water table could cause a change in the riparian vegetation, increasing the vulnerability of most of the trees that use the phreatic waters. In the case of elm forests, the danger of extinction due to global change is greater due to the appearance of Dutch elm disease. This disease seriously affected the size of its populations at the end of the last century. The rapid spread of the fungus was aided by the low diversity of the species, both in Spain and in other European countries. The domestication of this species as a result of its extensive use in clonal form by the Romans (Gil *et al* 2004), shows the need to avail of high levels of genetic diversity in order to respond to disturbances. There is a need to take measures to ensure the maintenance of their adaptive potential.

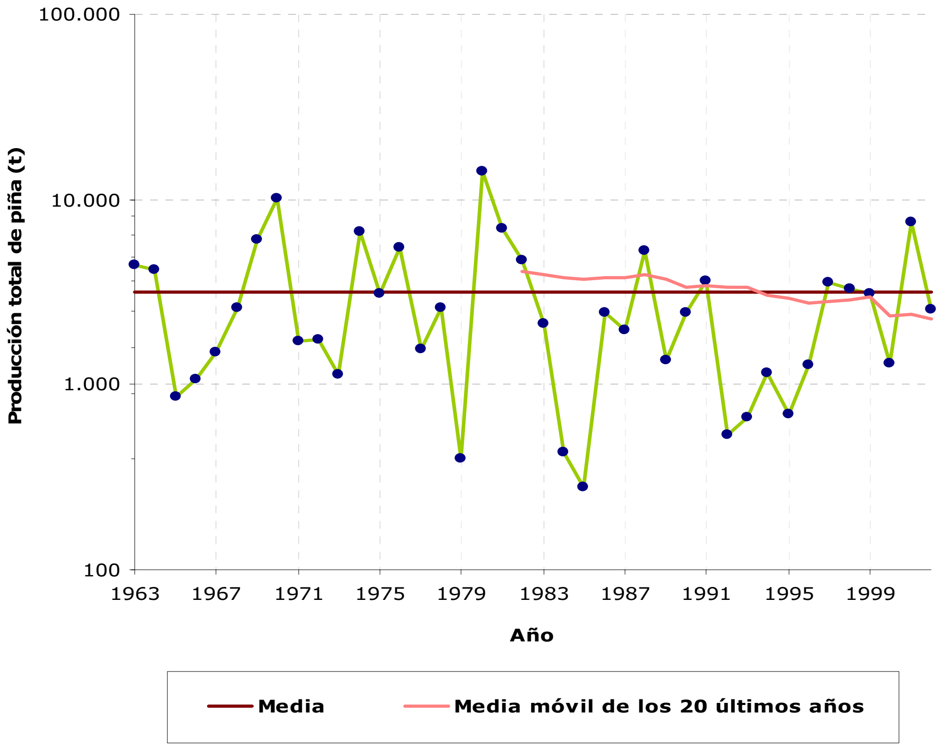

Fig. 9.7. *Irregularity of pine kernel harvests (tons) of Pinus pinea in public forests in public forests in the province of Valladolid, which presents a continuous decrease in the moving average in the last 20 years. Source: Gordo 2004.*

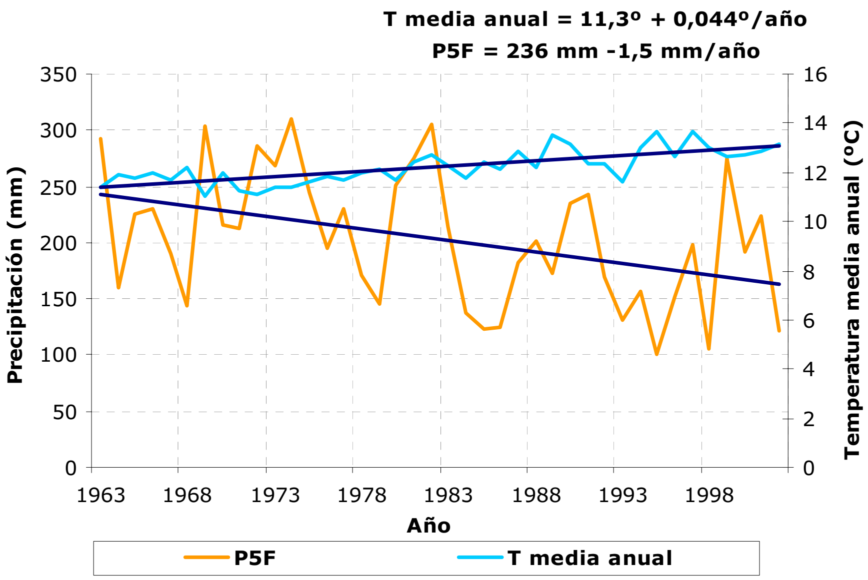

Fig. 9.8. *Evolution of annual mean temperature and of rainfall in the five months previous to flowering of Pinus pinea L in the Valladolid observatory. Source: Gordo 2004*

9.5. MAIN ADAPTATIONAL OPTIONS

9.5.1. Selective thinning of coppices and transformation into tall forest: an effective treatment for improving the response of forests to climate change

Many Mediterranean forest species are resprouting ones and some, like the Holm oak, develop large lignotubers in which the belowground biomass is accumulated, while the aerial fraction is burnt or cut more often. These differences cause a predominance of belowground biomass (over 50% of total biomass) over aboveground biomass (Canadell *et al*. 1997, 1999).. When the treatment of these forests is abandoned, the forest grows very slowly, because the high density of small-diameter trees leads to a situation very close to stagnation (Djema *et al.* 1994, Rodà *et al.* 1999, 2003, Hilbert and Canadell 1995, Sabaté 1993, Sabaté *et al*. 1992, 1994, 1995).

Fig. 9.9. *Experimental thinned plot in the Prades Holm oak forest. The reduced tree density of the stands modifies the water and carbon balance of the forest and has enables some of the possible effects that analogous environmental changes caused by climate change can cause in Mediterranean forests. More explanation in the text.*

In field experiments conducted in Holm oak forests in the mountains of Tarragona it was shown that in these conditions, the biomass accumulated causes, at this time of year, respiration to be greater than gross primary production, thus giving rise to negative net production rates (Albeza *et al*. 1996, Djema 1995). In order to survive, the trees deal with these conditions by using a fraction of the reserve mobile carbon.

If the unfavourable period is prolonged, reserves can be used up, first causing the destruction of the fine roots and defoliation and the subsequent death of the trees. The reduced aboveground biomass caused by the thinning treatment profoundly affects the water and carbon balances of the forest (Tello *et al*. 1994). Reduced leaf area considerably improves the hydric state of the remaining trees. The transpiration rate measures per unit of ground in the experimental treatment in Prades was around 400 $kg·m^{-2}·year^{-1}$ in all the plots, regardless of the density of the trees, which indicates an increase in the transpiration rate of the trees (transpiration per leaf area unit) in the thinned plots, which reduces the death rate during unfavourable periods.

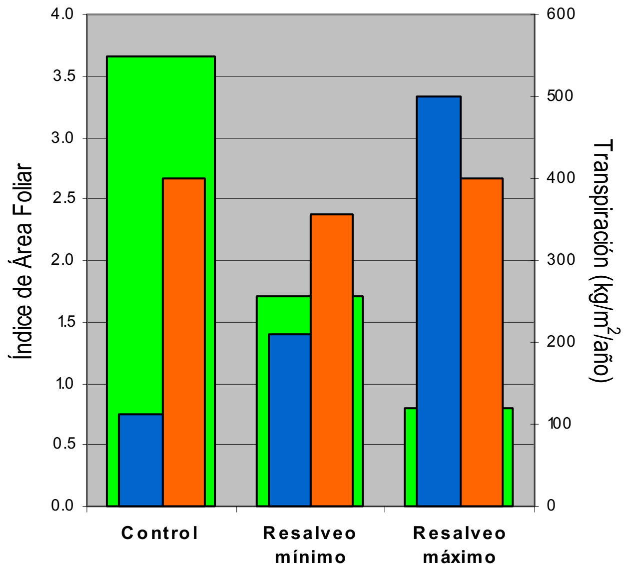

***Fig. 9.10**. The response by the Prades Holm oak forest to different thinning intensities (see figure 9.9) highlights the primordial role played by water in the response of the forest to structural or environmental changes and allows some of the responses that might be expected within the framework of climate change to be anticipated. The reduction of the leaf area index (green) according to the intensity of the treatment does not affect the transpiration rate per unit of ground area (orange, kg·m^{-2} de soil·year^{-1}). The reduced leaf index is compensated for by an increase in transpiration rate per unit of leaf area (blue, kg·m^{-2} of leaf·year^{-1}). The result, which has profound repercussions for the physiology of the trees, highlights the fact that water limitations restricts the growth of Mediterranean forests, and this, in turn, conditions all the responses of Mediterranean forests to climate change.*

9.5.2. Adaptive management: how to optimise the response of forests to climate change

The role of management in controlling the response of forests to climate change was studied in depth in the SilviStrat project. Succinctly, the project adopts three climatic scenarios basically corresponding to present conditions and two climate change scenarios predicted by the two general atmospheric circulation models (ECHAM4 and HadCM2). The growth of the forest is analysed combining these scenarios with alternative management scenarios. The objective is to establish the role of management in the different climate scenarios. The definition of management scenarios is based on the common management regime applied in each region. Using this base, the value of two variables is increased or reduced in a determined proportion: the period of time that elapses between two interventions and the intensity of these. Reducing the thinning interval, thinning frequency is increased, which involves greater intervention in the forest. The intensity of the intervention is defined according to the uncut proportion of the basal area at the moment of thinning. A parallel analysis was conducted of the effects of selective logging of the bigger or smaller trees or a combination of different diameters.

In the case of Mediterranean forest, we analysed the effects on Prades Holm oak forests (Tarragona) and Puechabon (Montpellier, France) and the Scots pine forest in Montesquiu (Barcelona). The results discussed here analyse the effect of increasing or decreasing by 33% the time interval between thinning interventions. The base interval upon which the 33 per cent variation was applied was, in accordance with the opinion of the managers 15 years in the pine forest and 20 years in the Holm oak forest. Analogously, the thinning intensity, expressed as the percentage of the basal area of the trees extracted, increased and decreased by a value of 30 per cent with regard to the habitual practices which are specific for each forests species.

With regard to management, it is clear that the effect of removing more or less basal area is much greater than that of modifying the intervals between successive thinnings. In the future climate scenarios (ECHAM4 and HadCM2), temperature rises and mean rainfall remains more or less constant, while the variability of this increases. In these scenarios, boreal and temperate forests present a positive response: there is an increase, albeit slight, in carbon accumulated in the soil, in the same way in which annual production increases, and therefore, carbon accumulated in biomass. In Mediterranean conditions, however, in which water is the most important limiting factor, the opposite effects can be seen. Analysis of the results show that the response of forests to temperature increase depends very much upon water availability. In conditions in which potential evapotranspiration is lower than rainfall, the temperature rise causes an increase in growth rate and in the carbon stored in the system. To the contrary, in forests in which potential evapotranspiration exceeds precipitation, the temperature increase tends to reduce the amount of carbon stored in the different compartments of the forest.

Table 9.5. *Carbon in aerial biomass (CAB, Mg/ha), carbon in soil (CS, Mg/ha), yield over a 100-year period (Y, Mg/ha) and fraction of available water not used by forest (WY, mm/year) in the PRADES Holm oak forest. The tables show the results of each variable under the three climate scenarios explored in the SilviStrat project in the nine management combinations defined in the management matrix. Ref represents the current management practices, ∇ and Δ represent the decrease and increase, respectively, in the management components (thinning interval and thinning intensity) discussed in the text.*

Thinning intensity

Thinning interval

		CRU			ECHAM			HadCM2		
		∇	ref	Δ	∇	ref	Δ	∇	ref	Δ
CAB	∇	34.9	31.0	27.3	39.3	35.3	31.9	38.0	36.0	31.1
	ref	35.5	33.2	29.1	40.7	35.6	32.5	41.7	38.5	34.8
	Δ	35.2	32.8	30.1	39.5	38.4	33.7	42.7	38.9	35.6
CS	∇	74.2	73.4	73.4	78.9	79.2	77.7	89.2	87.8	81.2
	ref	74.0	73.6	71.5	78.8	81.6	81.6	87.8	86.3	86.9
	Δ	74.7	75.1	74.7	80.0	77.9	79.4	88.4	90.5	90.0
Y	∇	76.6	102.8	124.4	105.1	126.1	172.6	137.4	149.4	200.4
	ref	71.6	86.9	109.9	92.6	106.6	110.8	118.5	48.3	143.6
	Δ	62.6	82.1	93.8	79.6	103.4	95.3	120.2	100.6	116.0
WY	∇	170.2	171.5	172.7	149.4	149.6	149.2	182.7	184.0	188.9
	ref	169.8	170.9	173.9	149.0	149.2	148.8	183.0	184.6	183.6
	Δ	169.7	171.3	170.7	148.4	149.7	148.1	183.1	182.2	182.6

Figures 9.11 and 9.12 summarise the results obtained from the analysis of 7 different species in 17 different sites throughout Europe. Growth was simulated under three climate scenarios and all cases of the aforementioned management matrix were applied. The baseline management corresponds to the current management system so that, in each particular case, the common practice is reproduced. Increasing thinning intensity and/or reducing thinning interval, leads to more severe management strategies (1 to 4) and, to the contrary, reducing thinning intensity and/or increasing thinning interval leads to more severe management strategies (6 to 9). A joint analysis of the capacity of forest management techniques to modify the response of European forests to climate change, conducted within the framework of the SilviStrat project, highlights the fact that the different management alternatives have hardly any effect when these are applied to European forests in restrictive growth conditions, represented by Mediterranean sites on one hand, limited by hydric deficit, and on the other, boreal forests, limited by low temperatures (figure 9.12).

Table 9.6. *Carbon in aerial biomass (CAB, Mg/ha), carbon in soil (CS, Mg/ha), yield over a 100-year period (Y, Mg/ha) and fraction of available water not used by the forest (WY, mm/year) in the pine forest of Pinus sylvestris in Montesquiu (Barcelona). The tables show the results of each variable under the three climate scenarios explored in the SilviStrat project in the nine management combinations defined in the management matrix. Ref represents present management practices, ∇ and ∆ represent the respective decrease and increase in the management components (thinning interval and thinning intensity) discussed in the text.*

Thinning intensity

Thinning interval		CRU			ECHAM			HadCM2		
		∇	ref	∆	∇	ref	∆	∇	ref	∆
CAB	∇	64.4	60.1	47.8	51.2	48.8	42.4	60.8	58.6	48.1
	ref	67.9	61.4	51.0	54.3	51.5	43.3	64.7	58.5	50.1
	∆	70.0	63.8	55.3	57.6	52.9	51.5	65.3	61.5	53.1
CS	∇	47.7	46.7	46.3	43.4	43.0	41.7	51.3	50.3	48.4
	ref	47.4	47.2	46.3	42.9	42.5	41.5	50.6	50.0	48.4
	∆	47.6	46.9	46.1	42.5	43.2	41.0	51.2	51.1	49.4
Y	∇	188.7	244.7	298.9	10.3	69.2	145.5	112.2	159.0	342.8
	ref	158.7	192.7	268.3	0.0	22.0	142.4	75.9	166.4	248.1
	∆	105.1	191.6	237.6	0.4	0.0	121.4	36.7	11.7	115.9
WY	∇	449.3	450.8	454.9	348.8	349.9	352.6	364.3	366.7	369.2
	ref	448.1	449.8	453.7	350.5	351.6	354.2	365.8	366.4	369.8
	∆	447.3	450.9	453.0	350.4	349.8	352.8	365.9	366.9	370.5

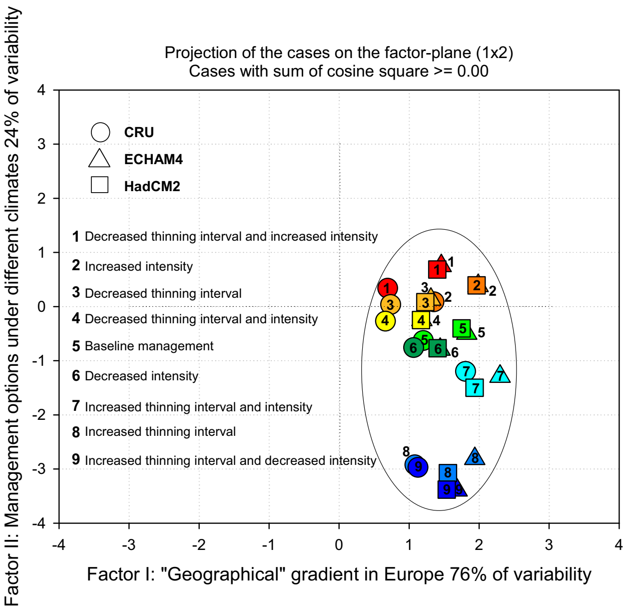

Fig. 9.11. *Example of a complete set of simulations of the beech forest in Fabrikschleichach, Germany. The baseline management corresponds to the current management system so that, in each case, the habitual practice is applied. Increasing thinning intensity and/or decreasing thinning interval leads to more severe management strategies (1 to 4) and, to the contrary, reducing thinning intensity and/or increasing the thinning interval leads to more severe management strategies (6 to 9). These management strategies are explored under three different climate scenarios: CRU, ECHAM4 and HadCM2.*

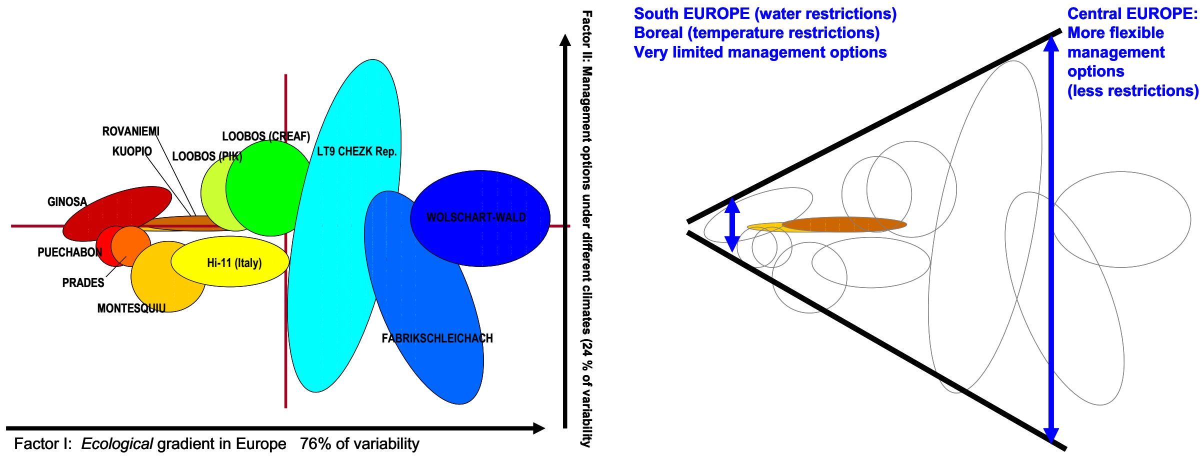

Fig. 9.12*. A joint analysis of forest management techniques to modify the response of European forests to climate change, conducted within the framework of the SilviStrat project, highlights the fact that the different management alternatives have hardly any effect when these are applied to European forests in restrictive growth conditions (represented by Mediterranean sites on one hand, limited by hydric deficit, and on the other, boreal forests, limited by low temperatures). To the contrary, the same management alternatives applied to central European forests present much more differentiated responses.*

9.5.3. Other adaptational options

The fact that practically 50% of the composition of wood is carbon witnesses the ease with which this is sequestered through accumulation in trees. Among the techniques involved are those that improve the productivity of the season, such as controlling the water table, or the recovery of this when it has descended due to agricultural use. Reducing the thinning interval, in particular of species with short rotations such as poplars, eucalyptus or *Pinus radiata,* will enable noteworthy increases to be obtained, due to the very short periods which contrast with those of Iberian species, as these trees represent the highest percentage of timber felled yearly. A similar action would involve the establishment of forest reserves with Iberian mountain conifers such as *Pinus sylvestris*, which currently are cutted much younger in relation to their natural longevity.

With the use of genetic improvement, we should promote, in the more productive species, the use of forest materials of selective reproduction, such as genotypes, origins or species that are more efficient in the formation of wood. Likewise, in other tree species, we should consider the use of material with carbon storage patterns altered towards location in the root systems, for example, the use of *Quercus pyrenaica*, given its capacity for root resprouting, which is an adaptation that enables subterranean biomass to be increased.

The recovery of large areas of degraded and treeless land by reforestation constitutes a priority action. To this end, species and origins must be chosen that are suitable for reforestation. Against the transformation to shrublansds of forest systems, planting rustic and heliophilous trees allows for horizontal stratification, which produced the biggest accumulations of biomass. Improvement of the original situation requires the subsequent application of forestry techniques in order to control the tree density of the forest and to prevent catastrophic disturbances such as forest fires, pests and diseases. These actions can be extended to existing forests.

Finally, the use of timber as raw material for the manufacture of products or for structural use in civil construction, constitutes another option for reducing the effects of climate change. Timber with heartwood or tannins in the case of pines, in particular *Pinus canariensis*, should be promoted, as they provide products with life cycles of great durability and high aesthetic quality. Additionally, in the manufacturing process, apart from being a naturally renewable product, wood consumes less energy than other materials such as bricks, glass, steel, aluminium or plastic. In this sense, we can highlight the use of cork, as opposed to other increasingly used alternatives, like plastic derivatives.

9.6. REPERCUSSIONS FOR OTHER SECTORS OR AREAS

The Forestry Sector as a generator of goods and environmental wealth influences the industries associated with commercial production. The ecological, recreational and landscape functions associated to these systems, and related to the leisure activities of urban societies and rural tourism, will be subjected to changes that are not easy to assess. Landscape is a subjective concept and the one we observe today is a product of our culture.

9.6.1. Timber industry

This sector supplies several industrial sectors such as timber, playwood, pulp or paper and furniture. Timber, because of its local nature, could be the worst hit, particularly that depending on Iberian mountain species, such as the Scots pine (*Pinus sylvestris*) or the beech (*Fagus sylvatica*), the use of which is very great at present. In the remaining sectors, a high percentage of the raw material consumed comes from fast-growing species, located on the Cantabrian coast or in clonal plantations in areas with a supplemental water supply. A deficit of these products would be compensated by imports, as a result of the little value given to these unmannufactured products and the important added value obtained in the transformation process.

9.6.2. Effects on hunting

Hunting is currently an essential element of much of the country's socioeconomy. As the main species involved are herbivores, this sector as a whole will probably not be greatly affected by climate change, but certain changes can be expected in the behaviour and distribution of numerous species subjected to hunting, with the consequent repercussions at regional level.

Specifically, there could be certain effects of climate change resulting from several different processes:

- Changes in the distribution areas of hunted species, according to direct ecological demand.
- Changes in the distribution areas of hunted species, according to changes in the structure of the ecosystems this inhabits.
- Changes in the aetiology of hunted species, especially in the case of migratory ones.

The first factor mentioned would have a direct effect, depending on hydric availability and temperature regimes, generally causing the spread of the species most associated with Mediterranean environments (for example, the moruna partridge) at the expense of those associated with Atlantic environments (for example, the pardilla partridge). Locally, especially with animal groups at their "range limit", this could lead to the disappearance of certain types of game in the area, decisively affecting biodiversity through the extinction of subspecies or varieties, as might have been the case of the stag in the cork oak of the Sub-Betic ranges.

Another series of influences might lie in the foreseeable changes in the structure of the ecosystems inhabited by the hunted species. In the last few decades, the general abandonment of practices typical of the traditional agricultural system, seen in the increase in forest area to the detriment of pastures and shrublands, is causing a notable increase in big game species, with small game species becoming rarer, except in areas with intensive agricultural activity. The limitations that the new climate regime could exercise over the re-colonisation of open spaces by trees or with regard to preventing closed tree canopies from becoming established in Mediterranean areas, could contribute to attenuating or inverting this tendency, thus favouring the small game associated with open structures.

The final series of changes refers to changes resulting from general climatic variation in the migratory regimes of numerous species. Certain bird species, that previously spent barely three months, during summer, on the Peninsula, such as quail, will progressively increase the length of their stay, even remaining in some of the warmer areas, as has been seen for the quail in some places in Andalucia. To the contrary, there may be a reduction of summertime migratory individuals associated with wetlands, due to their becoming rarer. With regard to wintertime migratory species, there may also be a downward tendency, but this will be intensely conditioned by changes occurring in their countries of origin. Lastly, we can expect changes that are difficult to predict in general migratory patterns, such as the abandonment of the traditional routes of pigeons in the Pyrenees and the North of the Iberian Peninsula, probably attributable to the frequency of early autumn storms in these areas.

9.6.3. Effects upon mycology

The changes to be expected in activities related to mushroom collecting will also be associated with direct changes in temperature and hydric regimes and with changes in the forest ecosystems where these activities are carried out. The most likely effect will probably involve variations in hydric availability in autumn, which will reduce the vital area of numerous species associated with rainy autumns. We must not, however, underestimate the possible effect of temperature regimes, especially because of the irregularity of these: brusque and out-of-season cold spells at the beginning of autumn are limiting the fruiting period in much of the North of such valued species as *Amanita cesarea*, whereas warm phases in autumn, winter and spring favour the rapid decomposition of many of the bodies generated and the rapid colonisation by parasites that devalue the product. In general, if the changes are sufficiently gradual, and if there is a certain continuity in the forests, we can expect the main groups to migrate northwards or in altitude, in search of conditions more similar to those currently existing in their distribution ranges.

9.6.4. Effects upon the cork sector

Influences in this field may, in turn, be variable, depending on the aspects considered.

- Distribution and condition of cork oak forests.
- Repercussions in the exploitation process.
- Commercial characteristics of the product.

The greatest influence will necessarily be exercised by the first of these three points, specifically because of the possible reduction of the existing cork oak forest area, which will drastically reduce the saleable stock of the product. We cannot ignore the death rate of cork oaks which, at the time, in 1995, was attributed to the complex episode known as the “seca” (dieback), and which has continued to act with surprising virulence over all these years in certain areas of cork oak forest in Cadiz, causing the death of big extensions of forest. Apart from this influence, we must also highlight the possible reduction of the exploitation season, conditioned by the last rains of spring and by the cessation of vegetative activity in summertime. Finally, the market tendency of the product will involve a general decrease in available sizes, which could involve increased peeling periods in some areas.

9.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

The series of results we have commented upon highlights some possible adverse consequences of climate change in forest ecosystems. There is obviously a degree of uncertainty associated with the complex analyses required to explore the effects of a complex change in itself, of which we do not yet avail of any details, in systems in turn as complex as forest ecosystems the biology of which is the result of interactions between numerous processes.

We need tools to help us to refine the analyses and in this sense, the administrations involved should make a big effort to compile and update the necessary databases. A paradigmatic example is the lack of information on the belowground biomass of our forests. We have seen that, in some cases, this biomass is greater than the aerial biomass, and therefore makes a crucial contribution to carbon balances. Hardly any information, however, is available on the biomass in the belowground compartment of our forests, and even less on the dynamics thereof. But, contrary to what should be expected, there are very few chances of finding funds for a competitive research project, aimed at extensively quantifying the belowground biomass of forests.

Another example of unsatisfied requirements involve forest inventories. The traditional design of national forest inventories aimed at quantifying *commercial timber stocks,* without considering the role of the remaining components (leaves, branches, bark, coarse roots, fine roots) which have been grotesquely termed “forest trash” by some uninformed technicians, should give way to designs based on a more modern concept of the forest as an ecosystem in which timber production is giving way, in some cases, to other alternative services, such as the frequently mentioned role played by forests, ,as a carbon sinks.

9.7.1. Biomass expansion factors

On building up national inventories of the carbon accumulated in forests, there is an obvious need to avail of values of the so-called biomass expansion factors.

Given that the objective of most forest inventories mainly involves determining trunk volume or biomass, in order to extend these measurements to other important components of the carbon balance of forests, such as roots, branches, leaves, litter or soil carbon, the so-called biomass expansion factors (BEF) have been adopted. The values currently used often involve another source of uncertainty and possible error, as, unfortunately, the databases containing extensive measurements of the aforementioned tree components are very scarce (FAO 2000, 2001). Apart from this problem, the transformation of data on biomass into carbon values also requires attention, as carbon proportion can vary among the different components of the tree or among different species.

The detail used to sample the 10,644 plots of the Ecological Forest Inventory of Catalonia (IEFC)(Gracia *et al*. 1992, 2000) has provided information on the biomass of the different tree components of the 95 species sampled. The resulting database (http://www.creaf.uab.es/iefc), with over two million records, represents the most comprehensive image of forests in the Mediterranean region.

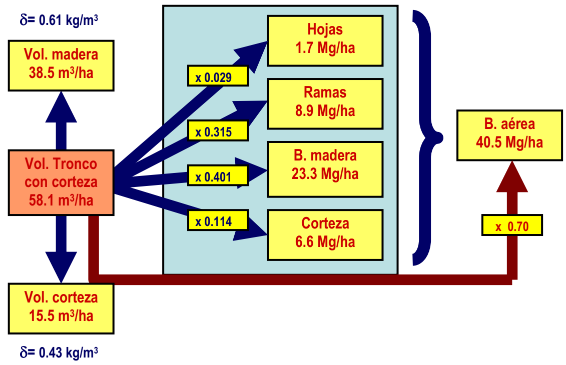

Fig. 9.13. *Components of the biomass expansion factors of he species: Quercus ilex (ileft) and Pinus halepensis (right). The data are based on the analysis of 1,666 Holm oak plots and 2,045 Aleppo pine plots. The most frequent variable in forest inventories is the volume of the trunk with bark and its two components: the volume of wood and the volume of bark. The specific densities of wood and bark enable biomass to be calculated. The biomass of the remaining components of the tree can be calculated by multiplying the volume of the trunk by the corresponding factors of each fraction. Multiplying the volume of the trunk with bark by factor 1.25 of the Holm oak (or 0.70 for the Aleppo pine) the total aerial biomass of the tree can be estimated, which is the basis for estimating carbon.*

This database was used to determine the biomass expansion factors of the main species. Figure 9.13 summarised the values of each one of the components intervening in the determination of the biomass expansion factors in the case of the Holm oak and the Aleppo pine. An estimate of the value of the aerial biomass expansion factor (ABEF) of the main species on the Peninsula can be consulted in Sabaté *et al* (submitted).

9.8. DETECTING THE CHANGE

9.8.1. Pests as bioindicators of climate variations

The presence of endemic pests and diseases is closely associated with certain forest formations: defoliators such as *Tortrix viridana* are associated with the genus *Quercus*, and they usually hatch coinciding with the development in spring of the buds of the host species. The modification of the plant's annual phenological cycle can influence the presence and abundance of this species, as well as its concurrence and competition with other defoliators, in relation to which its biological cycle is slightly advanced, such as *Lymantria dispar* or *Catocala* sp.

In the same way, certain perforating insects (species of the genus *Ips* in conifers) require the maintenance of certain moisture levels in the decaying wood in which they develop their larval and feeding galleries. The rapid desiccation of the plant material prevents these from being detected by the imagoes, hindering development.

9.9. IMPLICATIONS FOR POLICIES

9.9.1. Forest management based on the promotion of intra- and inter-specific diversity.

In general terms, forestry has traditionally been identified with the activity aimed at the establishment, conservation and commercial exploitation of forests. This may therefore appear to be unimportant from the environmental point of view, but the current objective of forestry management, without renouncing the commercial use, lies in the need for human intervention in order to maintain or re-establish the functional efficiency of existing managed forests.

According to the permanent forest theory, it is the forest that should establish the degree of intervention for the forestry manager, and not the other way round. This means that man's objectives should not prevail over the demands of the forest. This way of understanding the forest and the management thereof considers the forest as the subject of forest exploitation, and not the object.

Furthermore, the consideration owed to the forest as a space of public use, due to vital role it plays as a provider of goods and services of public interest, is not sufficient reason to defend the abandonment or non-use of forests, or non-intervention therein. If it is necessary to give priority to the long-term interests over the more immediate commercial ones, it is also true that the persistent and preconceived hostility towards the application of forestry techniques as the only way to manage the forest, with some claiming that non-use is the most efficient form of conservation, makes no sense, because, apart from not being based on coherent and realistic scientific arguments, it may not be legitimate or comprehensible in the technical sense, as it does not permit the forest microcosm to be observed as it really is, sometimes different from what we would like it to be.

It is at the meeting point between the maintenance and improvement of the biological functioning of forest systems, and the exploitation of the goods produced, commercial or not, where forestry management finds its place.

If, as has been previously mentioned, it is the ecological conditions that impose the type of management to be applied to a forest, then it is obvious that if these specific conditions were to change, there should also be a change in the type of management applied. The general idea is quite easy to take in, but in practice, climate-forest management relations operate within a broad context, which has not been quantified. With regard to vegetation, a significant climate change is considered to have occurred when conditions change in relation to quantity to the extent that the effects thereof cause modifications in the life/survival strategy of forest species, with a possible change in the dynamics and composition of the forest flora. This is when the existing vegetation, adapted to the previous climate, finds it difficult to survive in the new climatic conditions.

There are numerous studies of climate change, but few of them consider the phytological significance of these changes, which is the most interesting aspect with regard to designing strategies for mitigating the effects of the changes. Knowledge of vegetation and study of past climate allow the basic conditions to be identified. There is a certain degree of uncertainty, however, in relation to the characteristics of the final climate to which the present apparent changes have led or might be leading.

In general, the change tendency appears to indicate greater aridity resulting from a temperature increase and reduced rainfall. This tendency or change, when it occurs, is considered to be harmful to the vegetation in areas with a Mediterranean arid or semiarid climates. To the contrary, in areas in which thermopluviometric variations have no limiting effects, vegetation could be favoured, and there might be a consequent increase in productivity and even in diversity.

9.9.2. Promoting forestry interventions capable of mitigating the change

During the last drought that lasted from 1994 to 1995, numerous visual observations of forests were made in an attempt to establish relationships between the degree of mortality of the trees through drought and the type of forestry treatment being applied. On specific occasions, there appeared to exist certain cause-effect relationships, which rarely stood up to greater generalisation (Fernández and Montero 1993). Generalist studies that establish tendencies, generally weak ones, between forest density at a given moment and its response to a possible and not very well-determined climate change, are indicative and useful for establishing future behaviour patterns, but they certainly do not guarantee a quantified cause-effect relationship, not even within a broad interval of forest density responding to a quantified climate oscillation or change in similar terms.

It would seem that climate change does not yet involve a large-scale change in biological vocations (Allué 1995a, b). Only in some sites, with arid and semiarid climates, might there be any warnings of future climate. These cases might justify the initiation of forestry treatment aimed at absorbing the effects of climate change.

In order to design forestry actions, the application of which can be justified, there must be evidence that a climate change has occurred and that this will persist in the future and is considered to be incompatible with the existence of the present vegetation. Furthermore, we must also consider, where possible, the preservation of species of special interest, helping them, during a transitory period, to accelerate their adaptation, for example, by changing vegetative regeneration to sexual regeneration, modifying densities in proportion to the change occurred, etc. If the amount, persistence and/or speed of the change do not allow the vegetation to readapt to the new climatic conditions, forestry management alone will not be able to absorb the change process without incorporation large amounts of energy, such as irrigation, fertilisation and other types of protection, as is done in agriculture. In our opinion, the techniques for buffering the effects of this or of other processes should have a temporal horizon limited to the period of time that these effects last, the causes of which should be combated with the use of other types of measures.

To end with, in our opinion, uncertainties for the future can be dealt with, provided that we are aware that we will always have certain doubts. Management of forest systems could serve as a tool for transitorily absorbing the effects of the change. Reducing the tree sensitivity by selective thinning of trees could attenuate the effects of drought for short periods of time. If the change were to persist, it would become necessary to apply more complex forestry techniques, including the spatial-temporal programming of the forests, adapting intervention to determined moments of the life cycle of the species to be maintained or protected from the effects of the new climatology.

If the change is permanent and remains stable over time, it will become necessary to define a new type of forestry management adapted to the new climatic conditions and to the new evolutionary dynamics of the plant communities that have been established as a consequence of the changes. As always there will be a need to apply a type of forestry management appropriate to an ecological environment, accompanying and helping, on occasions, the evolution of the natural vegetation and not attempting to absorb the influence of natural factors affecting this environment.

9.10. MAIN RESEARCH NEEDS

9.10.1. Priority lines of research for learning of climate change and absorbing the effects thereof on forest systems

A. Basic aspects

- Quantification, structure and dynamics of the carbon accumulated in forest formations and shrublands. Aerial and root parts and carbon in the soil.
- Measurement of photosynthesis and carbon flow in forest systems.
- Models simulating biomass growth in forest systems, with particular emphasis on models of processes.

- Current carbon balance in the main forest systems and the possible influence of climate change therein. Consequences for forest management.
- Identification of the main eco-physiological factors limiting the natural regeneration of forests.
- Influence of climate change on vegetation displacement and modifications in plant cover.
- Evaluation of the adaptational variation among origins.
- Effects of climate change on forests. Design of indicators for detecting climate change for the establishment of early warning systems.

B. Applied aspects

- Experimental methods for estimating the aerial and root biomass of the main forest species, for rapid valuation as carbon sinks. Adaptation to the National Forest Inventory.
- Quantification of biomass expansion factors for the main forest species. Application to the National Forest Inventory.
- Development of methodologies for estimating biomass in shrublands and underbrush.
- Optimisation of management practices aimed at promoting the efficiency of forests as carbon sinks. Carbon forestry management.
- Application of forestry techniques for mitigating the effects of climate change in forests.
- Study for the partial substitution of construction materials obtained from highly pollutant processes by other, renewable natural resources.
- Estimation of the average life of the different forest products and the valuation of these as temporary carbon stores.
- Economic possibilities for energy use of forest waste (remains of cortas and others).
- Development of cultivo techniques and selection of species and clones for the creation of biomass for energy production.
- Agro-forestry cultivo techniques (agricultural crops interspersed among broadleaf plantations) as an instrument to satisfy the requirements of the Kyoto protocol.
- Study of the factors limiting the use of the forestry flexibility mechanisms established in the Kyoto Protocol. Emissions trading, MDL AND AC projects. Socioeconomic valuation, methodology and credit allocation.

9.10.2. Identification of future integrated projects.

The 2004-2007 National Scientific Research, Development and Technological Innovation Plan includes additional priority lines in the National Programme of Agroalimentarias Resources and Technologies, aimed at facilitating and promoting the contribution of the Agricultural Sector to reducing greenhouse gasses.

These research lines should be jointly studied by groups of researchers and experts from the Ministries of Education and Science; Environment; Agriculture, Fisheries and Foodstuffs; Industry and Technology, etc. The purpose is to define joint projects, consistent with regard to content and committed in relation to funding; thus, the Scientific Community will work towards solving specific problems that have been well identified by the specialists in charge of economic policies and management of energy resources.

The big electricity companies, or big consumers of energy should necessarily participate with the Scientific Community and with the Administrations involved.

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10. IMPACTS ON THE AGRARIAN SECTOR

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ABSTRACT

An increase in CO_2 concentration and air temperature, as well as changes in seasonal rainfall will have counteracting and non-uniform effects in Spain. The positive effect of CO_2 on photosynthetic rates can be compensated by greater temperatures and less precipitation. On the other hand, milder winter temperatures will allow greater crop growth rates if water is sufficiently available, and greater productivity in certain areas. Greater temperatures can increase evaporative demand, especially during summer, affecting irrigation requirements. In the South and Southeast of Spain, water demand could increase and thermal stress appear more frequently.

Crop simulation models using climate data from Regional Climate Models are nowadays the most efficient tools for impact analysis, as they are able to quantify the non-linear effects of climate change. Identification of regions differently affected is necessary.

Establishment of areas with different levels of impact and adaptation. Short term adaptation strategies can rely on simple management practices such as changes in sowing dates and cultivars. Nevertheless, in the long term, adaptation of cropping systems to future climate conditions is required. Implications on vegetable crops, fruit orchards, olive groves and vineyards should specifically addressed to assess adaptation at minimum cost.

The expected increase in extreme weather years will difficult crop management and will require more analysis of the sustainability of agricultural systems. Distribution and control of pests and diseases will differ. Their natural control during winter by frost and low temperature could diminish, so crop sequences would need to be adapted. With milder temperatures, current pests and diseases can be displaced to other latitudes and allow new problems too.

Effects of climate change on livestock are complex because of the diversity of the production systems as well as the direct and indirect effects on agriculture. Variations in temperature and precipitations will affect animal metabolism, reproduction and health issues.

Diseases produced by arthropods or helminths will vary in distribution, population and intensity, with different prognosis depending on the Spanish region considered. The epidemic control and the gravity and extension of the transmission process depend exclusively on the relations host-vector-environment, so effects on their biological adjustment are expected. Milder and wetter winters will increment significantly parasite survival. Parasite activity will appear earlier in the year due to milder winters. Dry and warm summers will increase mortality rates of arthropods due to loss of water.

Research is needed to predict the effect of climate change on the intake capacity and on the parameters indicative of animal welfare. With this information and previous experiences the construction of dynamic models could be possible. Also, the establishment of risk maps for each parasite is necessary as well as for the distribution of each parasite.

10.1. INTRODUCTION

10.1.1. Agricultural systems in Spain. Distribution, current area and productivity

Agricultural production in Spain contributes 12.1 % to the European Union's total production, behind France (23.1%) and Germany and Italy (both 15.4%) (MAPYA 2003, http://www.mapya.es/es/agricultura/pags/hechoscifras/cifras.htm). The most productive crop sectors, that contribute over 50% of national agricultural production, are, fruit and vegetables, vineyards, olive groves and cereals. A wide range of livestock products constitute around 40%.

Approximately 30% of national territory (50 Mha) is farmed or used for pastures. The diversity of productivity can be seen in the wide range of cereal yields across the peninsula and the contrasting high productivity of vegetable crops, the latter usually grown under irrigation and often within greenhouses. Productivity relative to water and nutrient use remains low in many parts of the country due to suboptimal management of soil, water, crop rotation, irrigation systems, etc. – but ways are known to improve performance.

10.1.2. Influence of the Common Agricultural Policy (CAP) in agricultural systems

The influence of the CAP can be seen in the crop sequences in both dry farming and in irrigation systems. Crop choices are not always the best in agronomic terms, especially in relation to climate and soil, so the sustainability of these agricultural systems is questionable. The progressive reduction of EU subsidies is beginning to affect management decisions, as can be seen in the restructuring and changing geographic distributions of olive groves and vineyards. Changes are also evident in the livestock sector, especially in mountainous regions of low productivity and changing environmental values, with evidence of increasing farm size and reduction in farm numbers due to amalgamations.

10.1.3. Components of climate change and basic principles of the impacts

10.1.3.1. Influence of climate change in the different agricultural systems

The possible effects of climate change on agricultural systems, discussed at length in the IPCC report (1997 2001a), indicated widespread and serious impacts on agriculture. Changes in CO_2 concentrations and in air (and soil) temperature, along with variations in seasonal precipitation, will have opposing and non-uniform impacts on the Iberian Peninsula, and in particular in Spain. That is to say, the impacts will be beneficial or harmful, depending on the nature of the agricultural systems and their locations in a peninsula of complex orography (Rosenzweig and Hillel 1998).

The nature of the opposing forces is well known. While, greater CO_2 concentration are expected to increase crop photosynthesis (e.g. Amthor and Loomis 1996) and reduce transpiration due to decreased stomatal conductance (Rodríguez *et al*. 2001), two responses that will together promote greater productivity and water-use efficiency, increasing temperature will have counteracting and compensating effects. Increasing temperature will increase thermal stress and reduce photosynthesis, especially of crops in already hot areas, for example of southern Spain, and will shorten crop cycles. The latter response will have the effect of reducing productivity and water use, although any savings in water may be offset by greater rates of water use in response to greater evaporative demand at higher temperature.

Change in total annual and seasonal rainfall is an important aspect to be studied in dry farming systems and in the design and planning of irrigation systems. Water demand must be adapted to water supply. Where insufficient water is available to meet crop demand, different cultivars or crops are required in dry farming. In irrigation, deficit irrigation may be needed to stabilise fruit and vegetable production in the various areas.

These simple considerations identify the complexity of the potential impacts associated with climate change and the need to identify those factors that are most critical to the productivity of Spain's varied agricultural systems. If the current crop management is maintained, crop life cycles will be shortened and flowering and maturation dates will change. Productivity and water use may increase or decrease depending upon interacting factors. This identifies the need for studies and individual analyses for vegetable crops, fruit orchards, olive groves and vineyards to identify least-cost adaptation strategies for crops, cropping sequences and management. This must be done with a clear understanding of the interdependence of agriculture with other sectors - hydrology, insurance (agricultural), energy (e.g. generation of electric energy versus use for irrigation) and the maintenance or expansion of areas for "natural" ecosystems, etc.

10.1.3.2. Influence of climate change in the different livestock farming systems

The implications of climate change for livestock farming (exploitation of animals for production) are potentially more complex than those for cropping systems. This arises because of the great diversity of livestock farming systems but also because climatic change will impact on both the animals and their feed base. Complex interactive effects are possible. The effect of climatic change on crop production is discussed elsewhere. For the animals themselves, variation in temperature and rainfall due to climate change can affect livestock in many ways (reproduction, metabolism, health, etc.), although these effects can be summarised in two parameters (intake, and animal wellbeing), which can be used as indicators of climate change in the different livestock farming systems due to their direct influence on the profitability of the farms. In extensive grazing systems, for example, climate impacts on fodder production but also on animal health and performance. In order to handle this complexity, the approach adopted seeks to establish the effects of climate change on parameters that are common to all production systems, and then to establish specific characteristics on individual systems

10.1.4. Analysis of possible tools for evaluating the repercussions of climate change in livestock farming

It should be pointed out that there are few studies in Spain of the influence of climate change on the aforementioned parameters (intake, and animal wellbeing). Although scientific-technical information does exist in relation to the influence of temperature in nutrition and stress in animals, and these results could be used as an initial working reference.

The clearest and most direct effect of climate change is upon the availability of fodder throughout the year, which conditions intake and the profitability of livestock farms. In this sense, a change in rainfall distribution in grazing areas would lead to a reduced amount of pasture, and, which is more important, to a reduction of potential grazing time, which would lessen the carrying capacity (cap/ha). In these systems, variations in available plant matter and carrying capacity could constitute two tools for evaluating the effects of climate change.

In intensive systems, the tools to be used are the parameters indicating the degree of stress in animals (levels of cortisol, adrenaline, ionic balance, etc.) and the effects of this on the production parameters of farms.

10.1.5. Data on Iberian ecosystems, area and types, and suitability for animal pathology

There are two main aspects of diseases in domestic animals that are particularly sensitive to the effects of climate change and are clearly distributed with regard to ecosystem or habitat. One of these is related to parasitic diseases that depend on the particular biology of certain parasites. Indeed, all arthropods (fundamentally flies, mosquitoes and ticks) depend completely on environmental climate to modulate their biological cycle. A given area may be appropriate or not for a determined arthropod (the disease thus appearing or not), depending on the delicate balance of certain climatic variables which will subsequently be dealt with. Other parasites, such as helminths or worms (etiological agents of widely distributed diseases in Spain) can have free stages. All the epidemiology of these helminthoses is regulated by the variables temperature and humidity, and life cycles are once again based on prevailing conditions (Soulsby 1982). It must also be kept in mind that arthropods are vectors of a great deal of other processes, both parasitic and infectious, with serious economic repercussions for animal health. The epidemiological regulation and the seriousness and extent of the process transmitted depend exclusively on the host-vector-environment relationships, and obvious effects on the delicate biological balances of complex processes are therefore to be expected (Lindgren 1998).

Thus, the effects of climate change can be expected to be seen in all those parasitic and infectious processes, the etiologic agents or vectors of which are closely related to climate. Arthropods are temporal parasites. This implies that the parasitic phase constitutes only a fraction of the total duration of the parasite's life cycle. Under these circumstances, climate has a predominant regulating effect. Each species of arthropod has a variable number of phases in its life cycle, depending on the species or even on its taxonomic group. Thus, Diptera (flies and mosquitoes) usually have a larval form that hatches from an egg. The development speed of the egg depends exclusively on prevailing temperature. Above and below certain critical temperatures, development is interrupted. Furthermore, mortality in this phase derives from relative humidity, or, to a lesser degree, from the deficit of atmospheric saturation. A high deficit implies a high death rate, responsible for great population losses. As with the Diptera, it could be said that this regulation of the embryonic phase is identical for ticks, which form a group of Arthropods separate from the previous ones, but with important implications for the health of domestic animals (Estrada-Peña 2001). In both groups, the egg develops and the larva hatches. In some cases, this larva develops in water (some mosquitoes), in others it can be an animal parasite (certain flies) and in others it develops in the environment and only temporarily parasitises the host (as in the case of ticks). It is in the latter case that the most evident effects of climate change on their life cycles are to be expected, for two reasons. On one hand, the larvae of ticks are exposed to environmental climate for almost 99% of the duration of this stage. Besides, the larval phase in ticks is responsible for the whole complex numeric population regulation of the rest of the tick's life cycle (Gray 1982). A high death rate in the larval phase would cause a drastic decrease in tick populations. Likewise, a huge increase in numbers during this stage, would lead to a dramatic rise in the numbers of the parasite in the field.

All of these effects should be considered not only from the point of view of an increase or decrease in population, but also in relation to sanitary conditions and to the potential transmission of different diseases to the animals (Randolph *et al*. 2002). Indeed, we cannot contemplate parasitic disease without observing the immune response of the host, which is explicitly adjusted to the parasitic pressure it is subjected to. Changes in this pressure appear to be accompanied by subtle but profound variations in the response the animal presents to the hostile environment constituted by the parasite.

One of the most obvious effects can be seen in the adaptation of the parasite to its habitat. The suitability of the habitat depends on the adjustment of a series of climatic variables to certain possible preferences of the Arthropod. The other effect derives from changes in the seasonal dynamics that are to be expected as a consequence of the acclimatisation of the pathogenic agent (parasite) to the changing climatic situation. Studies carried out with ticks, which are ideal indicators of climate change, have demonstrated two fundamental details of the effects of climate change. On one hand, milder and wetter winters cause a clear survival rate of certain stages of the parasite's life cycle. These milder winters also cause an advance in the time of year in which the tick commences its activity, due to the fact that the duration of the lower temperatures that prevent activity by the arthropod is shorter, and the life cycle is therefore extended (Randolph *et al*. 1999). There is, however, another effect that should be mentioned here, related to hot, dry summers. These summer periods are believed to increase the death rate among ticks, which is a simple question of water loss. The effect that climate change will have on two important factors for ticks is still unknown: soil and vegetation, as it is here that their life cycles take place, and where the effects of climate are modulated. In other words, the effects of climate change on the biological cycles of these arthropods will be complex, and will give rise, as will be described in the chapter on “impacts”, to a whole new relationship between ticks, climate and animals.

As has been mentioned, there are also other parasites whose life cycles are highly influenced by climate change. Normally, several larval phases of the parasites known as nematodes (parasitic worms found in domestic and wild animals and in man) are exposed for long periods of time to environmental climate conditions in the grass (Almería 1994). As with arthropods, and as in the aforementioned specific case of ticks, nematodes have optimum temperatures, different for each species, at which development of the species is maximum. Above and below these temperatures, development speed is lower, and can even come to a halt. This is the case of winter temperatures and of the larvae of these nematodes in the grass. Low winter temperatures cause the metabolism of these nematodes to slow down or to stop. Although in certain parts of Spain, there are sufficiently high winter temperatures to maintain a level of development which is low but above zero, and although each species prefers a different optimum interval, it can be said that these winter processes cause an adjustment in the life cycle, so that development of infestant forms coincides with the appearance of pastures for the animals in springtime.

Other parasitic entities which are expected to be modulated by the effects of climate change are included within the helminthosis transmitted by freshwater snails. Although the larval forms of the agents causing these processes as less associated with the environment as free stages, like the aforementioned arthropods or helminths, the fact that they are transmitted by freshwater snails implies that modifications in the fresh water spots profoundly affect the transmission cycles of these helminths. Indeed, snails acting as vectors of these entities also need a series of finely tuned environmental factors for their development. Likewise, the parasite cannot develop inside the reservoir snail without the right combination of temperatures for its development cycle. Regardless of the geographic variations that can occur in the maintenance of the water spots necessary for the survival of the snails (see chapter on continental waters), changes in water temperature can be expected to cause variations, as yet unquantified, in the development, spread and distribution of these helminthosis.

10.2. SENSITIVITY TO THE PRESENT CLIMATE

10.2.1. Sustainability of systems and stability. Indicators of impacts on agriculture. Current state of basic resources (soil, water, genetic information)

General studies of the agriculture sector that have been requested by official organizations such as the *United States Department of Agriculture* (USDA) (Reilly *et al*. 2001) emphasise not only quantitative estimates of changes in production, water use, etc., but also the problem of variatiability. In the case of the Iberian Peninsula, and Spain in particular, this is one of the most critical issues, because the stability and sustainability of any system is affected by interannual and seasonal variations in rainfall, water availability for irrigation, the greater or smaller frequency of frost in springtime or the torrential rains that have especial impact on the fruit and vegetable sector.

10.2.2. Variability in water supply (dry farming and irrigation)

Dry farming systems and pastures encompass most of the farmed area, and therefore comprise the major agricultural resource base of the nation. It is critical that this resource base be maintained so that adverse effects of any land-use practices can be corrected. As climate changes, this may require not just changing management practices but also land use, either towards an increase in area, towards afforestation, or towards an increase in the area under irrigation. Increased variability in the supply of rain or irrigation water, could initiate a process of change previously unexperienced in these systems.

The availability of water for orchards, olive groves and vineyards is a crucial theme for study, and requires close connection with the other sectors involved in this project. A fundamental step is an estimation of water demand, i.e. evapotranspiration (ET), by crops in future climates. One of the most difficult questions involves the transfer of predictions of variation in precipitation to the water available to crops, in particular vegetable crops.

10.2.3. Importance of extreme years and events (water, pests, diseases)

In the case of Spain, greater frequency of years with low rainfall, more storms or longer heat waves (see chapter 1) will have many effects on the population and their activities, including farming. Farmers will have to adjust their short-term tactical management and long-term strategic plans. The rigid rules under which they now receive financial aid, or subsidies from CAP, will need adaptation to new conditions if they are to assist and not hinder the essential process of adjustment.

In particular, there is a wide and variable distribution and scope for deleterious effects of pests and diseases in the economically important crops. Changes in temperatures or in relative humidity or rainfall will affect the way in which appropriate adaptations can be implemented (IPCC 2001a). Natural control that is currently possible, for example low winter temperatures in some areas on the Plateaux, may diminish so that solutions may require modifications to crop rotations. On the other hand, temperature changes will allow current pests and diseases to be displaced to new areas and also allow new problems too.

10.2.4. Importance and evolution of the different livestock farming systems in relation to land use

In general terms, changes in the livestock farming systems in our country in the last few decades have led to increasingly intensive systems, as a result of the fact that from the 50s to the 80s the objectives of animal production were based on reaching the maximum possible amounts, as rapidly and cheaply as possible. At the time, this objective was logical, as it was intended to cover the existing needs (meat and milk, fundamentally) of the population. This approach based upon maximising production is easier to achieve in intensive systems with farms with a large number of animals, and with more homogeneous production. Furthermore, in these decades, the traditional grazing areas (for instance, mountain areas) were abandoned by the population, which led to a decrease in the number of livestock farms and changes in the traditional uses (sustainable) of the territory, because of the integrating factors of the production system, the factor land gave way to the human factor (labour), the most important one.

Of the work carried out in the Montaña de León mountains (Serrano *et al*. 2002) the changes indicated in the livestock farming system in this area were characterised and quantified, and evidence was seen of the viability of production alternatives, because this area now produces highly prized, top-quality livestock products. Although the dependence on economic subsidies threatens the feasibility of some of these farms, except in the case that the aid received was linked to a rational use of the territory in order to avoid unfair competition from other production systems, which in spite of receiving economic aid, do not benefit the environment.

In mountain areas, livestock farming systems traditionally coexisted which were based on different species of herbivores (cattle, sheep, goats and horses) with mixed production (milk, meat, wool, work, etc.). Changes in recent years have led to a big increase in livestock farming systems producing beef, and the practical disappearance of the other systems, with a direct effect on land uses and changes in plant cover.

10.2.5. Data on main environmental features and current climatic tendencies involving the presence/absence of a pathogenic process

(See section 10.3.3.)

10.2.6. Relatively stable seasonal patterns and cycles that change drastically over short time periods

(See section 10.3.3.)

10.2.7. Foodstuffs quality

At present, no evaluation exists of the effects upon the quality of foodstuffs. These effects could be related, for instance, to: transfers of periods with high temperatures and the protein quality of hard wheats (pasta production), changes in rainfall patterns during the maturation process of the grape, greater nutrient leaching in intensive systems with irrigation, such as vegetable crops. We are, however, aware of the effects of frost temperatures on the quality of agricultural products and the consequences of excessive temperatures or of heat waves on production, like what occurred during the heat wave in the summer of 2003. We are aware of the consequences, but what now interests us is to know whether the frequency with which these phenomena occur will be altered in a scenario of climate change.

10.3. FORESEEABLE IMPACTS OF CLIAMTE CHANGE

10.3.1. Dry farming and irrigation-based agricultural systems

The first studies of the impacts of climate change on agriculture systems in Spain made use of General Circulation Models (GCM) to provide input data for crop simulation models. The GCMs considered came from: the *Goddard Institute for Space Studies* (GISS), the *Geofluids Dynamics Laboratory* (GFDL), and the *UK Meteorological Office* (UKMO). This allowed the first analyses to be made of the impact of climate change on biomass generation and yield, and on the water consumption and irrigation needs of certain crops (Iglesias and Mínguez 1995, Mínguez and Iglesias 1996). The low resolution of the GCMs, however, did not allow differences, that exist in the present climate between neighbouring regions, to be applied to crop production scenarios.

The second stage was initiated with the use of GCM models with atmospheric-oceanic coupling (AOGCM, specifically HadCM2) together with a regional climate model (PROMES) with greater resolution (see chapter on Climate). The crop simulation models used are included in the *Decision Support System for Agrotechnology Transfer* (DSSAT) v. 3.1. (Tsuji *et al*. 1994)

These are the models of the CERES group, *Crop Estimation through Resources and Environment Synthesis* (Ritchie and Otter 1985; Jones and Kiniry 1986; Otter-Nacke *et al*.

1991). Wheat (winter) and maize (summer) were selected as reference crops because their growth cycles covered all the seasons of the year and because, with different photosynthesis systems (C3 and C4), included different responses to CO_2 increase in the analyses.

The impact of climate change was assessed in terms of changes in water use and crop yields for the summer and winter growing seasons. The methodology used, along with some of the impacts on water consumption rates, are described in Guereña *et al*. (2000). This study was the first in Spain to use data from a RCM in crop simulation models and the first to make a comparative study between impacts derived from low (AOGCM) and high resolution (RCM) models. This study describes changes in yields, biomass, evapotranspiration (ET) and the irrigation needs of "reference" crops.

A current research project is PRUDENCE: *Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects* (EVK2-2001-00156) (see also Chapter on CLIMATE). This study attempts to evaluate the uncertainties associated with predictions of change in climatic parameters, and to evaluate how the predictions are transferred or reflected by the impact models. The impact models are either crop simulation models (DSSAT, Tsuji *et al*. 1994) or models of cropping systems, CropSyst (Stöckel and Nelson 1994).

The studies are again being applied to winter and summer cereal crops, with and without irrigation. Fig. 10.1 shows the simulation of impacts through the changes in yield of a cultivar winter-grown farming barley under rainfed conditions, without irrigation, in present climate ("*current*") and A2 (see chapter 1), future, generated by the systems simulation model CropSyst connected to different regional climate models: RCM, ETH, GKSS, Promes, HIRHAM (see chapter 1). The commercial cultivar used requires vernalisation (exposure to low temperatures to induce flowering) was assessed in north, central and southern Spain under both present and future climates. The results reveal yield impacts that include crop. This comparison enables the testing of the sensitivity of the models in the present climate.

10.3.1.1. Use of General Circulation Models (GCM) for climate, with low resolution and crop simulation (DSSAT). (studies for the National Hydrological Plan)

During the years 1998 and 1999 some initial studies were carried out for *the Centro de Estudios y Desarrollo Experimental* (CEDEX) – Centre of Studies and Experimental Development – on the impact of climate change upon irrigation systems (Mínguez *et al*. 1998; Mínguez *et al*. 1999). In the design of the National Hydrological Plan, the importance of establishing the future trends of water demand by the Agriculture Sector led to the initiatiation this collaboration. These studies showed the usefulness of climate and crop models as evaluation tools, highlighted the spatial variation in the impacts and the need to work with high resolution (RCM+Impact models).

Estimation of the impact of climate change was based on the irrigation needs of maize, as a summer crop, and of wheat, as a winter crop. The scenarios were generated by the General Circulation Model (HadCM2) for 250x250 km. grids. This initial approach revealed the need for higher resolutions for the Peninsula, because the response to conditions of higher temperature and variations in precipitation, in some cases predicted threefold increases of maize yield, very high biomass production and abnormally low harvest indices. The irrigation needs of maize were smaller in the future climate, in spite of the temperature increase, due to the shortening of the crop cycle and to the increased rainfall predicted by the general circulation model. In some cases, predicted rainfall exceeded 1000 mm per year.

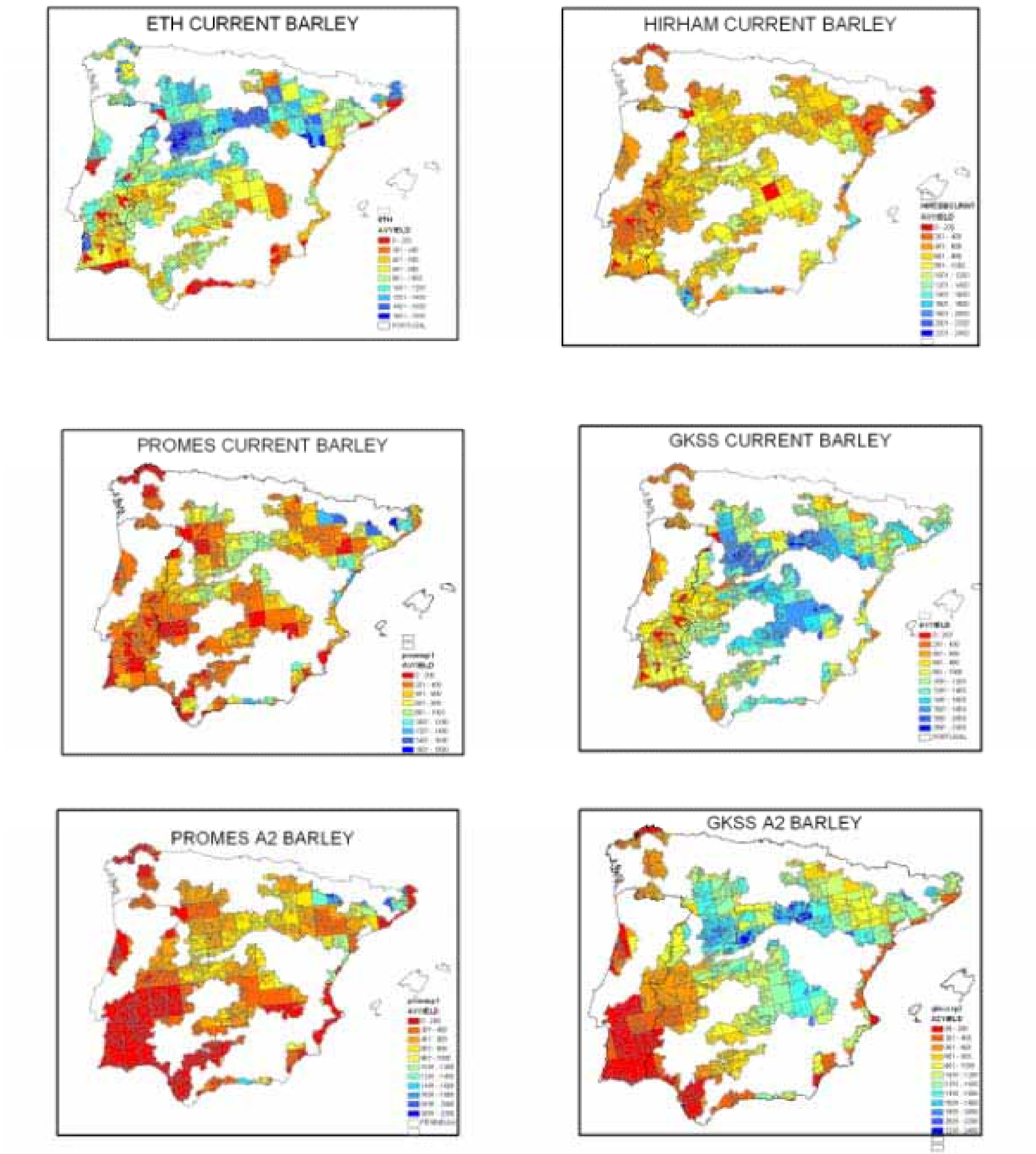

Fig. 10.1. *Simulation of impacts through changes in dry farming barley yields, unirrigated, under current or control climate scenarios and A2, future, generated by the crop simulation model CropSyst connected to different regional climate models*

10.3.1.2. Impacts on phenology and on crop yield and biomass

Within these previous studies, and in the absence of adaptation strategies by farmers, the major response is the acceleration of phenological development and the shortening of vegetative. However, responses of crop yields and biomass production vary among zones.

If the climate models have low resolution (see Fig. 10.2) it is difficult to establish trends of crop performance. In some areas, yields and biomass production under irrigation remain around potential production, although increasing in some cases in the winter cereal. Temperature increase in areas that currently have cold winters, and greater solar radiation and rainfall in most cases, operate to prevent yield loss. For example, in Fig. 10.2, in the blue cells, the grain maturation time of maize is advanced by 13 to 44 days, with great variation between locations (cells). Whereas grain yield decreases in cell 2-2, it increases threefold in 4-4 and by just 20% in 3-3.

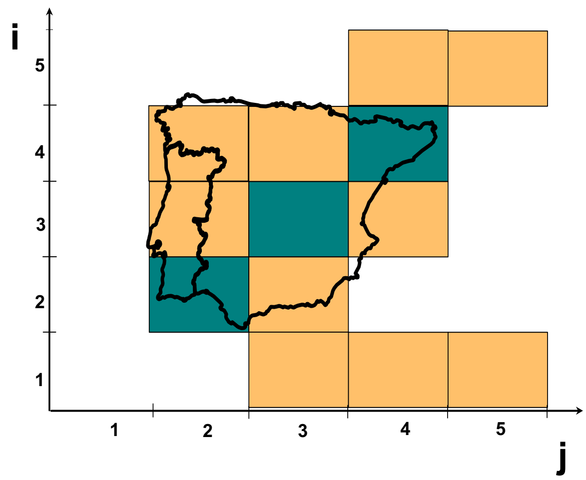

Fig. 10.2. *Cells (i, j) showing the resolution of the low resolution AOGCM models in most of the previous studies, including those by the IPCC*

The studies currently being carried out with higher resolution climate models (Fig. 10.3) enable us to demarcate the areas positively and negatively affected by changes in precipitation and temperatures.

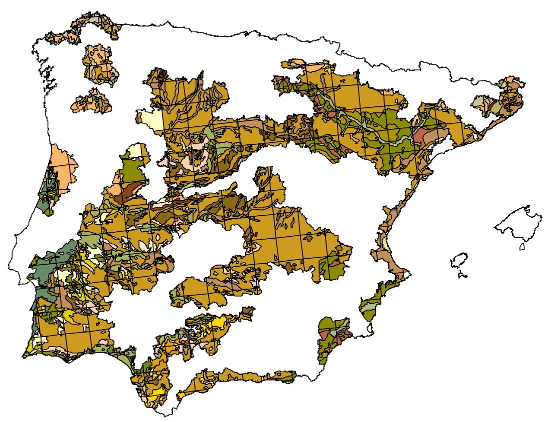

Fig. 10.3. *Soil map of the agricultural areas currently being studied. The superimposed mesh shows the cells corresponding to the Regional Climate Model (RCM) PROMES*

10.3.1.3. Water consumption by crops

The evaluation of changes in water consumption by crops was made for the CEDEX (see this Chapter, section 10.3.1.1). Fig. 10.4 highlights the smaller irrigation requirement and yield potential of maize caused by the severe shortening of the vegetative. The strategies that might compensate for the effect of the shorter are not shown. The negative impact of greater daily evapotranspiration, a consequence of the higher temperatures, can, however, be counteracted by more rapid development and by more efficient water use in an environment with a higher CO_2 concentration.

10.3.2. Livestock farming systems

10.3.2.1. Effects on ingestion of food by animals

From the point of view of nutrition, and as a consequence of the need to release the heat produced in the energy metabolism of the animals, if environmental temperature surpasses the interval of thermal neutrality, ingestion by the animals will be reduced; the temperature values defining this interval depend on the species and on its physiological state. The relationship between the temperature values involved in climate change and the references of intervals of thermal neutrality allow initial ideas to be established in relation to the possible impact on ingestion by the animals. Climate change can also affect the animals' ingestion indirectly, on conditioning the evolution of the availability of pastures throughout the year. In this sense, botanical diversity, altitude, etc., should be taken into account when evaluating the repercussions of climate change.

The behaviour of grazing animals with regard to intake is also directly conditioned by environmental temperature. In this sense, when temperature is high, for example, in the middle of the day in summer, grazing activity is practically zero, this being transferred to the start and end of the day and during the night.

10.3.2.2. Effects on animal wellbeing

Society is obviously interested in a type of animal production that respects the animals' rights to be bred in conditions of minimum stress. This fact, which initially appears to be relatively abstract and difficult to evaluate, can in fact be measured by analysing concentrations of certain substances in the bloodstream (cortisol, for example), as well as the incidence of pathological processes in the animals, resulting from the immunosuppression caused by stress.
One of the causes of stress that has most frequently been indicated is the variation in environmental temperature. The degree of influence of this factor on the wellbeing of animals is variable, and they can even die if suitable body temperature is not maintained.

10.3.3. Parasitosis with free life stages

In view of what has previously been stated, the types of impacts to be expected will subsequently be indicated. It ought to be pointed out that there is a limited number of studies involving a determined impact, and in some cases, we only avail of different laboratory studies under controlled conditions, in particular the life cycle of parasites, based on which deductions can be made with regard to the effects of determined types of climate change on the biology of the parasite and the epidemiology of the disease.

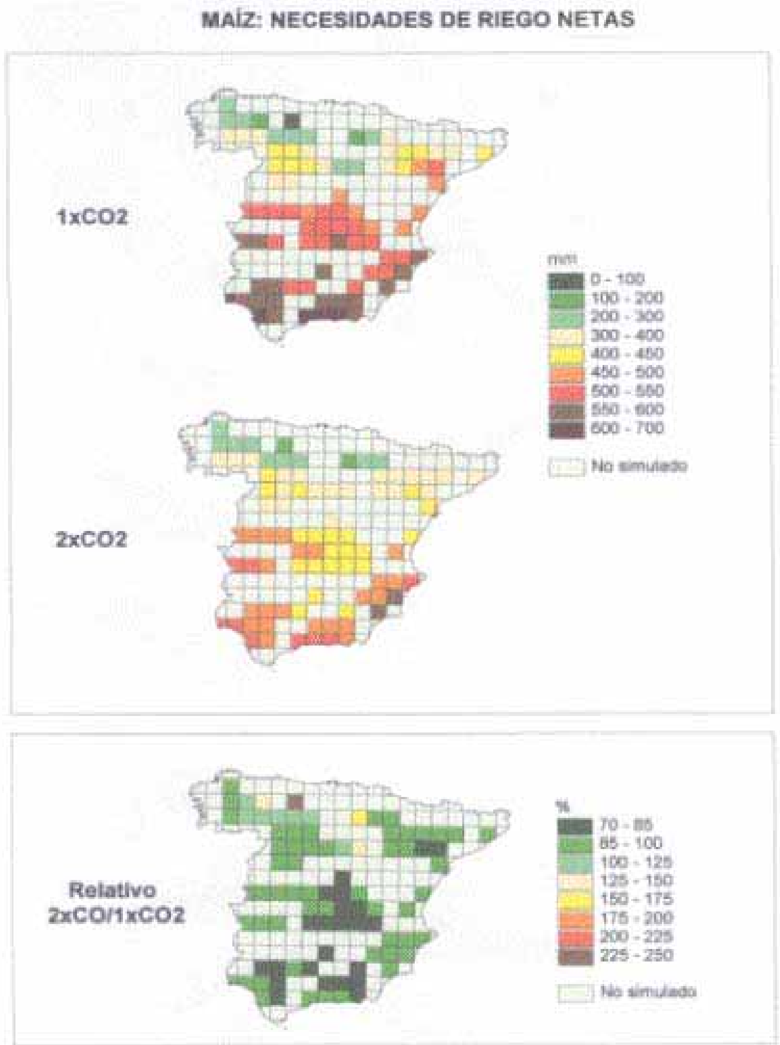

Fig. 10.4. *Studies of the impacts on the irrigation requirements (necesidades de riego) of maize, using previous versions of the climate model PROMES and the crop model DSSAT (CEDEX 1999). Irrigation corresponds to total net irrigation requirements and the adaptation strategies are not shown (e.g. changes in varieties)*

10.3.3.1. Seasonal accentuation of life cycle patterns of parasitosis with free life stages

Milder winters and increased rainfall would cause a lower death rate in all parasite populations, which would be seen in greater population numbers in springtime. This would mainly affect those animals starting to graze at this time of year. It should be remembered that young animals start to graze for the first time at this time of year. The immune system of these animals is deficient due to their age, which would cause substantially greater economic losses, resulting from the higher death rate. But this parasite population increase in winter, and the consequently high springtime parasitic load can also cause a greater summertime parasitic load, resulting from the high reproductive success of the pathogenic agents during spring. This would generate an abundant population for summertime. Although this population is expected to suffer a high death rate due to the temperature increase and to the low relative humidity to be expected during summer, the big number of individuals will cause a greater population availability during autumn. In short, the foreseeable climate changes will cause a series of changes in parasitosis at temporal scale, apart from the aforementioned geographic one, among which we can highlight:

- An increase in parasite populations during spring.
- An increase in the parasite load per host, with greater economic losses due to decreased production or death. Increased treatment costs.
- Appearance of parasite populations at times of the year in which these are not habitual.
- Application of medicaments at times of year considered optimum for treatment, but not valid in the predictable new patterns of seasonal dynamics. Error in the application of the treatment and new increases in the costs associated with the disease.

10.3.3.2. Colonisation of new areas, previously free from any given parasitic or infections processes

This type of impact derives from changes in the geographic distribution of parasitosis. Areas in which certain parasites are common would cease to be a suitable environment for these, which would disappear. Other areas that are currently free from determined parasitosis, however, could foreseeably be invaded by these. Whatever may be the case, an altitudinal and latitudinal deviation of the parasitosis influenced by climate is to be expected. For example, determined species of ticks currently existing in areas in the south of the Peninsula could move northwards, settling previously uninfested areas. In this sense, an increase in altitude can be applied in particular to valleys. Whereas a determined process may now be common in valley bottoms, the predicted climate changes may cause them to move to greater elevations. This would involve a radical change in the way animals are managed, specifically in relation to the management type known as “mountain pass transhumance”. In this type of management, large herds of animals are moved to the highest zones of mountain passes, in search of fresh pastures, free from parasitosis, due to the effect of the low winter temperatures currently observed at these altitudes. The rise of parasitosis to high-mountain pastures at greater altitudes, however, will cause a profound change in management practices. We can expect to observe this altitude effect both in helminthosis and in the processes produced and transmitted by ticks. All this will cause three clear impacts of a geographic nature:

- Increased diarrhoeic processes caused by helminths in areas where they are unknown or rare at the present time. Changes in classical treatment patterns.
- More problems caused or transmitted by ticks in areas in which they are currently unknown or rare.
- Exacerbation or disappearance (depending on the species involved) of these processes in the southern areas of the Peninsula. We should highlight the phenomenon related to the appearance of “new” diseases in areas where they were previously unknown, with the consequent problems involving diagnosis and treatment by veterinarian staff in these areas.

10.3.3.3. Substitution by parasite species on colonising areas abandoned by endemic species (immunity problems for the livestock maintained in the affected areas)

One of the effects expected is the one known as “species substitution”. In this case, parasite species that were common in a given area (to which the animals have adapted as a result of a long period of coexistence) disappear because they have not adjusted to the new climatic conditions. These species, however, are substituted by others that have been displaced for the same reasons, to which the animals have no humoral or cellular resistance. Thus, the livestock maintained in these areas is negatively affected.

10.3.3.4. Appearance of resistance to antiparasite treatments

when man is faced with an unknown situation involving parasites (seasonal change or population increase, or the appearance of new processes) his only response involves applying treatments. This higher therapeutic pressure causes the response of the parasite populations, which involves a brusque increase in the genetic selection of the population subjected to pressure by the antiparasite treatment. Resistance to the antiparasite compounds is a serious situation, and we lack the most basic measures to prevent the parasites from appearing or to re-establish the sensitivity of the parasite population to treatment.

10.4. MOST VULNERABLE AREAS

10.4.1 Dry farming systems. Arid and semiarid areas. Maintenance of soil quality. Erosion. Traditional olive groves

Dry farming systems are still the most widespread ones and the quality of the resource base should therefore be maintained in order to facilitate changes towards possible extensification, forestation or, on the other hand, intensification of the system. Within the forecasts associated with low resolution climate models (AOGCMs) these areas are the ones presenting the biggest negative impacts (IPCC 2001a). Greater resolution is needed in climatic parameters in order to discriminate in which areas the effects will be additional. These systems generate less crop residues, so soil cover is therefore low (Díaz-Ambrona and Mínguez 2001), and residue return may be insufficient to maintain soil quality.

10.4.2. Irrigation systems. Salinity and nitrate pollution

There is great demand for water in the south and southeast where fruit and vegetable production is concentrated, and where risk is high due to the low quality of irrigation water, suffering from marine intrusion into aquifers and from nitrate pollution.

Strategies for the recovery or maintenance of present water quality should be planned under future climate scenarios. For this, a fundamental step involves estimating the water needs of crops (evapotranspiration, ET) in future climate conditions. Also, one of the most difficult tasks is the transfer of forecasts of variation in precipitation to crop water supply, particularly the vegetable crops.

10.4.3. Coastal areas and marshes

A rise in sea level and possible changes in sea currents would affect cultivated marshlands. Analysis of impacts in these areas must be made in collaboration with others responsible for studying responses in coastal areas. The same applies to river mouths and deltas that would suffer changes in recharge flows, in turn causing alterations in sediment deposits and in water quality. A gradual temperature rise in coastal areas would cause a concomitant I increase in crop water demand that would exacerbate the pressure on water supply sources. In particular, increased irrigation, from subterranean waters would increase the risk of marine intrusion in coastal aquifers.

10.4.4. Distribution of livestock farming systems (extensive versus intensive) throughout the different regions

By way of an outline, intensive livestock farming systems are located in areas where there is local production of fodder for the animals or fundamentally, close to consumption centres, or where there are feasible channels for marketing the products.
Figure 10.5 se presents the distribution of the most important livestock farming species in Spain.

Apart from a few quantitatively unimportant exceptions, pig and poultry livestock farming is done intensively, on big farms with a high degree of technology.

Cattle for milk production has undergone changes towards more intensive systems, with an increase in the size of the farms and the virtual absence of grazing at the present time. Sheep breeding for milk production is in a transitory situation, and is becoming more intensified, and the farms on which the animals are permanently stabled, with no grazing involved, now represent over 30%.

Still based on the grazing system are fundamentally the cattle and sheep systems for meat production, but we should take into account the limited profitability of these calving cow production systems in intensive conditions.

10.5. MAIN ADAPTATIONAL OPTIONS

10.5.1. Change in systems

It is necessary to delimit the different areas of the Peninsula in order to establish broad lines of adaptation. The opposed effects of climate change could cause the environmental conditions in parts of the Peninsula to improve, whereas the negative effects might be disastrous for other areas.

Specific studies are also needed for more inert systems, such as crops of woody species. The olive, vineyard, citric sector and the fruit sectors in general, require knowledge of the associated tendencies and degrees of uncertainty, which will vary according to areas.

Agricultural systems will adapt towards the extensification or forestation of the areas in which instability is increasing, or where EU subsidies, if these are maintained, promote this. Intensification or stabilisation by means of irrigation constitute another possibility to be analysed.

10.5.1.1. Choice of species and varieties

The introduction of new crops under new climate conditions should be approached, in the first instance, from a strictly agronomic point of view. The initial approach would be based on productivity and the optimisation of water use. Cultivars with longer life cycles could be introduced to counteract the accelerated development resulting from higher temperatures. This step establishes crop options that can be subsequently reviewed with respect to aid or subsidies by the Common Agricultural Policy (CAP).

In the case of plantations of woody species, temperature increases, more extreme summers or the displacement of rainfall periods will lead to a reconsideration of the choice of varieties in the different agricultural regions, if we consider that reduced springtime frosts are expected.

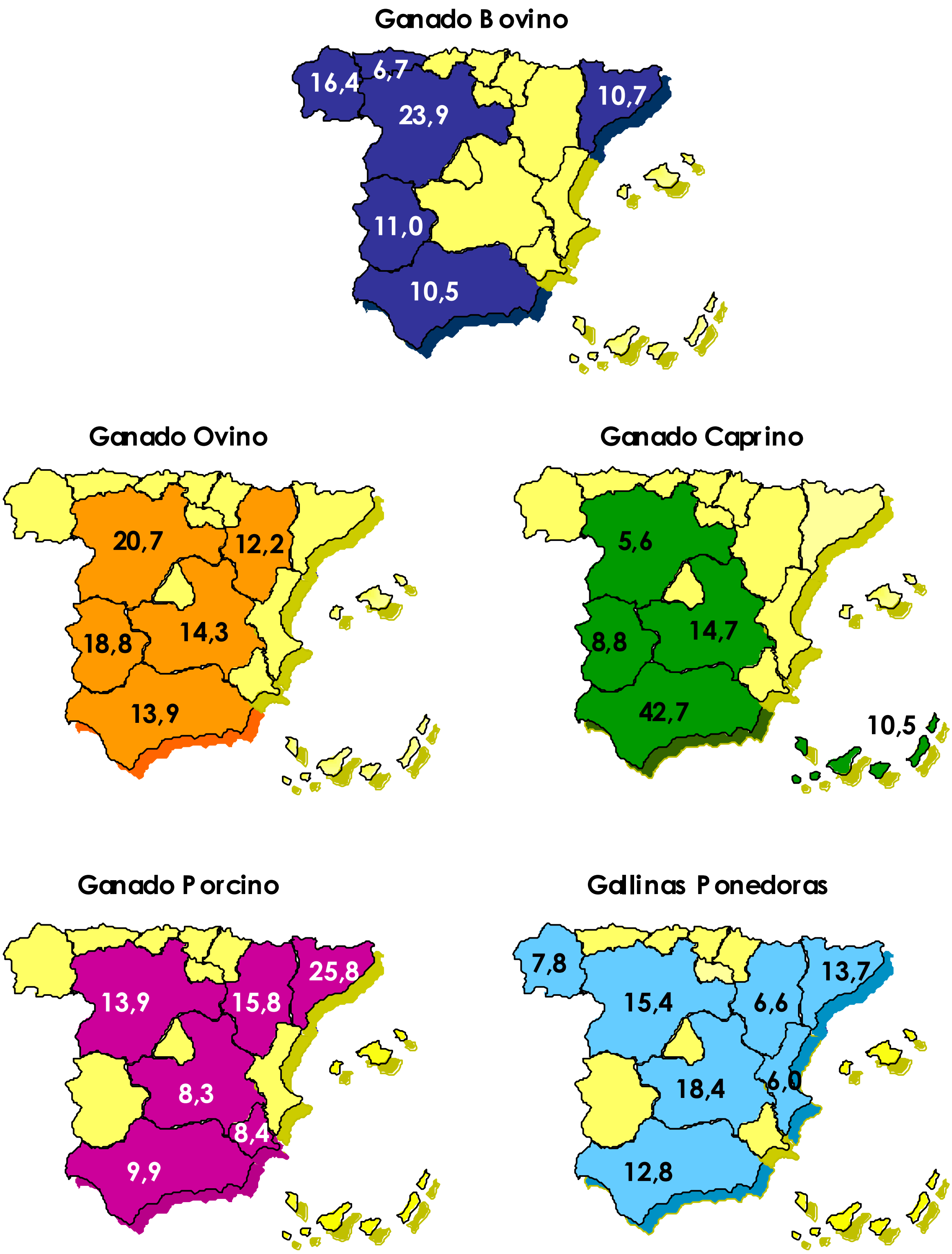

***Fig. 10.5**. Distribution map of livestock inventory (Livestock survey 2003, MAPA)* (Cattle, sheep, goats, *pigs, laying hens)*

10.5.1.2. Changes in crop rotations

In areas where water is the limiting factor, sequences that optimise water use will have to be established. New areas should be delimited where agronomic fallow is vital for maintaining the stability and sustainability of the systems.

10.5.2. Adoption of new dry farming and irrigation management strategies

Once areas have been demarcated according to predictable impact, changes can be considered in cultivars, sowing dates and irrigation requirements. These are strategies that have already been well explored and which the farmer can easily adopt. Emphasis should be placed on strategies for the optimisation of resource use that have a minimum impact. Extensification (lower inputs), strategic or support irrigation and deficit irrigation are developing technologies that ought to be applied in such new environments.

New integrated design may be needed for the control of pests and diseases, as these organisms respond to future climate change.

10.5.3. Adaptation of the Common Agricultural Policy (CAP)

Collective regulations are considered by the IPCC (2001b) as one of the tools for mitigating the impact of climate change and possibly for reducing the costs of the adaptation processes. The CAP could therefore be considered within this perspective.

10.5.4. Reduction of livestock carrying capacity

The alternatives that could be considered, in view of reduced ingestion as a result of climate change, and those that would need to be contrasted previous to being applied, are the following:

- Reduction of the animal carrying capacity (heads of livestock per area unit).
- Increased needs for supplementation in grazing systems.
- Changes in the management of grazing systems.
- Higher energy and facilities costs for the maintenance of correct environmental temperatures.

10.5.5. Protecting areas against changes in uses

The effect of temperature increases, apart from those of variations in rainfall, involve a northward displacement of areas suitable for crops (as we have seen in the case of maize, wheat or barley), and above all, of vegetable production. This displacement should be evaluated, because to the direct effect of climate change on a determined areas can be added the loss of competitiveness compared with others, which can accelerate the process of transformation and abandonment of agricultural activity in sensitive areas.

10.5.6. Appraising the suitability of the habitat and invasion capacity through studies of climate and habitat

The expected climate change will cause a variation in parasitic and infection processes, as has been previously mentioned, both in space and in time. The best adaptation to the changing scenario cause by climatic variation lies in the knowledge of the precise biological and abiotic patterns regulating the association between the parasite, the pathogenic agent it can transmit and the environment. In this sense, an absolute priority involves the development of simulation models that can account for different data on the behaviour of the agent in relation to the environment, such as its capacity to adapt to the biotype (maps predicting the risk of determined pests) and models explaining the seasonal dynamics of the process to be studied. Likewise, the models should include estimates of the economic implications to be expected in the case of the different evaluable climate change scenarios. Likewise, the simulation models should include the landscape component, understood as the ecological processes occurring at microscale, which is very useful for evaluating the composition of the habitat as a determinant factor of the existence and abundance of the parasite. In this sense, we wish to insist upon the fact that models based on large areas of territory (macroclimatic models) can be of great epidemiological value, but that we must come down to the microhabitat scale, with the complexity that this involves, in order to understand the real effects of climate change on parasite populations. In relation to the models dealing with the behaviour of tick populations, important advances have been made which enable the predictable effects to be explained to a great degree. These models, however, need to be generalised to other species and to the whole geographic environment of Spain, and the resolution of the model must be increased to functional level.

There is a need for the imbrication of the models of host behaviour or of the modifications climate change can cause in vegetation, in order to obtain a broad view of the parasitic, ecological and epidemiological processes underlying climate change and acting, above all, upon all the members of the equation. Thus, a generalist model is needed, linked to general climate predictions and to the effects of changes in vegetation and in the parasite dynamics affected by these variables.

In the case of parasite nematodes, these models already exist, but the are not public, having been developed by private companies as a market strategy. It is important that these models be applied to the research sector, in order to establish suitable adaptation strategies. Furthermore, models dealing with parasitosis transmitted by freshwater snails have been suitably developed and linked to geographic information technologies, and they have a simple form of treatment, producing results that are clearly comparable with reality. These technologies, however, have never been applied to studies in Spain, and we therefore lack minimum data on the effects to be expected in conditions of different environmental variables.

10.5.7. Appropriate management, integrated into the results of the previous points, using autochthonous breeds

The use of autochthonous breeds is a correct decision with regard to optimising the control of the different parasitic and infectious diseases appearing in Spain. The breeds present a natural adaptation to these processes, resulting from a long history of coexistence. The substitution of imported breeds by autochthonous ones should therefore be considered as an interesting strategy of adaptation to climate change and to the effects of this upon predictable pathologies.

As has been mentioned, it is important to appraise the possible impact of the different management strategies derived from these models on the livestock farming economy. Factors such as the nutritional value of pastures should be highlighted. As has been pointed out, changes can be expected in the way agricultural resources are used by the animals and by their owners, tending towards the search for new areas that present a parasitic load appropriate for animal management. We should therefore take into consideration the economic factors intervening in the new relationships between animals and their habitat, as an integral part of the aforementioned models. It is also necessary to include studies of the patterns involved in antiparasite treatments, because the farmer, or veterinarian, is familiar with the life cycles of the parasites in the area in which the animals are farmed. This knowledge is almost ancestral, and is based on the continuous observation of nature. If the foreseeable variation in these processes occurs, both in space and in time, the currently established treatment patterns will be radically altered. This involves a process of adaptation by the veterinarian and by the breeder, according to the intensity of the impact, gradual, and to the exponential change to be expected in the response by the parasitic and infections processes. In other words, the time in which the adaptation will take place is expected to be a short one, and we should prepare the necessary evaluation tools to deal with the social demand that will occur during this readjustment period.

10.6. REPERCUSSIONS FOR OITHER SECTORS OR AREAS

10.6.1. Environmental impact: quality of the resource base and of the natural ecosystems

Changes in soil organic matter are difficult to predict, given the impact of management on crop residues and the complexity of the processes involved (see chapter 8). In a future scenario, predictions of water content in the soil would add another source of uncertainty. Soil organic matter directly affects the capacity for water retention and nutrient supply, with direct implications for the productivity of the system. In the areas capable of producing a greater amount of biomass, higher soil temperatures could counteract the increase in organic matter through higher mineralisation rates.

The greater runoff associated with storm-related phenomena or increased precipitation promote greater nitrate leaching, reducing the efficiency of the system and possibly affecting neighbouring ecosystems and agricultural systems. Projections based on general circulation models for Spain suggest areas with both increased and decreased annual runoff (IPCC 2001a). Higher resolution models are required to resolve these uncertainties.

10.6.2. Water demand and competition with the industrial, environmental and urban sectors

An increase in world population and in economic development generally leads to greater water consumption, in spite of a decrease in some countries, due to more efficient use (IPCC 2001a). This implies that the competition between the industrial and urban sectors with irrigation (see section 10.1.3.1) will be defined by changes in the evapotranspiration demand of the crops in response to temperature and rainfall.

Furthermore, the new demands on water supply to maintain ecological flows and the necessary resources in wetlands, lakes, etc., will also affect the availability of water for irrigation. It should be emphasised that water markets will have to adapt to an increased variability that water demand for crops might present.

10.6.3. Main repercussions for the foodstuffs and insurance sectors

The consequences for the foodstuffs sector at international level are serious, if we analyse the capacity of the agricultural systems to supply the food needed by a growing population. In this sense, we wish to highlight the more short-term repercussions for the insurance sector.

Changes can be expected in the type of damage that crops might suffer. Higher temperatures will eliminate the risk of frosts in certain areas, which will need to be identified, and will minimise it in others. The risks associated with hydric stress and temperatures will tend to increase, although it will probably be necessary to establish these probabilities according to determined areas or catchments.

Changes in the geographic limits of current crop distribution may lead to the appearance of pests and diseases in new areas. If the frequency of extreme years increases, collaboration will become necessary between the agriculture and insurance sectors, in order to establish new lines of proposals.

10.6.4. Effects of livestock farming on the maintenance of the rural population and the landscape

In many parts of the country (mountain, *dehesa*, etc.) livestock farming is practically the only activity capable of maintaining an economic tissue, as other activities such as agriculture are impossible due to climate conditions, orography, etc. At present, it seems obvious that the livestock farming in this area will have to be based on products (food, leather, wool, etc.) that can be differentiated on the market, and of guaranteed quality (traceability), and there is a growing demand for these products, because consumers are increasingly willing to buy products based on suitable conditions of animal wellbeing, or, based on grazing livestock, which has obvious benefits for environmental conservation and which makes use of resources that would otherwise be lost. The development of mass production systems in these areas would make no sense, because of the risk to the environment involved and because of the lower level of competitiveness due to being so far prom the cereal production areas. Less available pasture at certain times of year, resulting from climate change, could lead to overgrazing and to the risk of erosion in these areas, as it is not easy to vary the pressure applied by grazing (livestock carrying capacity) by decreasing or increasing the number of animals.

The number of family-held livestock farms that can be maintained in a determined area depends on their profitability, aimed at providing a minimum income for the family in question. In turn, the profitability of a farm depends on the number of animals and the production of each one of these. In order to achieve a similar income, for example, a cattle farm with mixed production (meat and milk) requires less animals than a farm that exclusively produces meat, due to the lower level of individual production of these. In recent years in the mountain regions of Aragón, Castilla y León, Catalonia, etc. There has been a restructuring of the livestock breeding system, leading to more big farms exclusively producing meat, which require less labour, and the use of the territory is not a limiting factor, due to the depopulation of these regions.
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10.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

10.7.1. Effect of increased variability on the stability and sustainability of agricultural systems. Effect of extreme years

The more unstable and less sustainable agricultural systems could disappear with an increase in the frequency of extreme dry years. Furthermore, a possible increase in storm-related phenomena similar to those of subtropical climates could increase the erosion of agricultural soils that are still managed with conventional tillage. For instance, current estimates of soil erosion in olive groves are excessively high, and could reach 40 t/ha year.

10.7.2. Capacity for adaptation of low productivity systems

At present, water deficit, low temperatures of long winter seasons and low organic matter content are the factors most characteristic of systems of low. The capacity of these systems for adaptation will therefore depend on the areas in which these systems are located and the predicted trends of changes in rainfall and temperature.

10.7.3. CO2 fixation capacity of agricultural systems. Influence of land and crop residue management

In order to mitigate climate change, (IPCC 2001b) have proposed reductions of CO_2 emissions. CO_2 fixation by herbaceous and woody plants through photosynthesis is one of the processes considered. Studies currently focus on estimates of net CO_2 fixation, the respiration associated with the maintenance and growth of plant biomass, and fixations and emissions by the soil, depending on the management of soil and of crop residues.

Further sources of emission of greenhouse gasses are flooded rice fields (methane and nitrous oxide emission) and the losses of nitrous oxides associated with nitrogen cycle processes in agricultural systems.

10.7.4. Adaptation capacity of the animals

Animals have defence mechanisms for adaptation to climate change that have direct consequences in terms of production. In intensive conditions, the adaptation will involve lower production rates, as the capacity for intake could be affected if the limits of the thermal neutrality interval are surpassed. Furthermore, under these circumstances, there may be a need for greater availability of space, ventilation or cooling systems, etc., and consequently, greater investments.

In extensive livestock farming systems, which depend on the availability of pastures, the possibility, within certain limits, of the body reserves of the animals being used as energy storage at times of maximum availability of resources, to be saved for times of scarcity, together with an adaptation of physiological rhythms, which would make the times of maximum nutritional need (end of gestation and start of lactation) coincide with maximum availability of pastures, are mechanisms the limits of which ought to be studied from the point of view of production.

10.7.5. Reaction times to change by parasites

At present, the response time lapse of parasites to climate change is unknown, but it is believed that the reaction would be rapid. Some laboratory studies indicate that this response could occur in one or two generations of the parasite (approximately one year), which would involve the disappearance of species that have not adapted to the new climate in this period of time, with a slower substitution by the new invasive species. Given that climate change is gradual, the aforementioned seasonal accentuation, as well as species displacement, can be expected to occur gradually and continuously.

10.7.6. Indicators

The only indicator of usefulness is the constant supervision of a series of “reference zones” chosen for their climatic characteristics, their capacity to accommodate determined parasite species, and livestock farming use. Monthly sampling in these areas can allow parasitic activity to be monitored in order to establish the modifications taking place.

10.7.7. Low spatial precision

This is one of the most serious problems in the evaluation of models that study climate change and its consequences for the population dynamics of parasites. Current climate change models evaluate big atmospheric units, 50 km being a typical unit size, which is extremely large for the models that are currently being evaluated in order to predict changes in pressure by parasites.

The characteristics of the habitat are of great importance in the distribution and abundance of certain parasitosis (for example, ticks, Estrada-Peña, in press), and systems should therefore be found that link both types of models, together with those that evaluate the probability (normally with Markovian-type methodologies) of change in the type of habitat. There is a need to evaluate the possibility of downscaling in atmospheric climate models, and to link them to those dealing with habitat change and parasite behaviour.

10.8. DETECTING THE CHANGE

10.8.1. Difficulty to detect changes: technological adaptation in agriculture

The adoption of new technologies in agriculture has prevented the detection of possible trends or changes in climate over the last century. Modifications in cereal crop cultivars in the 60s, during the Green Revolution, led to spectacular increases in yields, and production thresholds were raised in agricultural systems around the world. New irrigation and fertilisation techniques, as well as the control of weeds, diseases and pests have all contributed to much higher yields.

10.8.2. Use of dynamic crop and climate simulation models. Generation of indicators

Dynamic crop simulation models are capable of providing daily information on the processes of interception of solar radiation by leaves, the generation and partition of biomass,, balances of water and nitrogen, and finally, the generation of yield. The capacity to quantify interactions between crops, specifying cultivar, soil and climate, makes these models very powerful tools for both research and agricultural planning and development. Although these models were developed initially for herbaceous crops, more recent development includes versions for woody crops also.

The results obtained from these models of yields, biomass production, water consumption, irrigation needs and phenology are now used to calculate indictors that integrate interactions on productivity and performance throughout the crop cycle (Díaz-Ambrona and Mínguez, under review).

10.8.3. Availability of production data on livestock farming systems over long time series

The dynamic models used in studies of livestock farming systems enable a prediction to be established of the response by the animal to changes in environmental conditions (humidity, temperature, etc.) in housing conditions (intensive).

Under grazing conditions (extensive) it is also possible to predict the effects of climatology (humidity, temperature, etc.) on the response by plant production in a determined area throughout the year. Based on the available quantitative and qualitative information of plant matter, it is possible to predict ingestion rates by the animals, and, having established the animals' needs throughout their production cycle, it is also possible, through extrapolation, to establish to what degree these needs have been covered and when food supplementation is needed, when the animal carrying capacity should be reduced or when there is a need to establish land use systems aimed at making use of the different availability of food throughout the year (for example, the classical systems of livestock transhumance).

There now exists scientific-technical information that would allow for the creation of these models, but there is a lack of available data on animal response over long time series, which is practically non-existent, as the available information, for example, on variation in animal inventories in the different regions, is provided by a host of converging factors.

10.8.4. Indicators (key species such as mosquitoes and ticks)

There is a series of parasites that respond rapidly to climate changes, such as mosquitoes and ticks. Suitable monitoring of these parasite populations, in a series of key sites (chosen for their ecological characteristics) could facilitate a real evaluation of the impact of climate change on this groups of parasites, and help to establish the importance of these factors in the transmission of infectious processes by these vectors.

10.9. IMPLICATIONS FOR POLICIES

10.9.1. Changes in Common Agricultural Policy (CAP). Incentives for the adoption of technologies with less environmental impact in future climate scenarios. Agricultural insurance

Co-ordinated action by several countries can help to reduce the costs associated with the development and implementation of mitigation strategies. The CAP can be considered as the framework for future collective regulations promoting the innovation necessary for adaptations (IPCC 2001b).

Incentives for the implementation of crop systems with less environmental impact in the present climate constitute one of the first steps for assisting transition to crop management systems in future climate scenarios. Indeed, the environmental impact of inappropriate management of land or crop residues, inefficient use of water for irrigation, nitrate pollution, etc., that are currently a concern, will have more serious affects in scenarios of greater seasonal or interannual variability andr water deficit.

Agricultural insurance in Spain could constitute one of the pillars able to sustain specific agricultural systems in areas subjected to the negative impact of climate change.

10.9.2. Land planning

The division of climate change into large impact zones, both positive and negative, would be a basic step for hydrological planning and for other resource-use issues. The productivity of the various agricultural and crop systems in each distinct zone would facilitate the establishment of action proposals.

10.9.3. Optimisation of water uses. Management of water resources

Given that the Iberian Peninsula, and specifically Spain, is located in a transition zone between subtropical and Mediterranean climates that, according to IPCC (2001a), are affected differently by water shortage, the issue of water management is likely to provide the most complex challenges. Management of water distribution among the sectors involved should give priority, among other fundamental economic and social considerations, to the systems that optimise water use, measured as the water-use efficiency of rainwater or that used for irrigation. Water planning should include analyses of such quantifiable concepts as sustainability, productivity, stability and equity of the systems.

10.9.4. Changes in animal management

The effect of climate change on livestock farms has the peculiarity of coinciding with the aforementioned tendency towards an intensification of livestock breeding systems. It is in these systems, which are becoming increasingly intensified, that the economic repercussions of climate change are greatest, as they will lead to reduced yields and an increase in investments aimed at counteracting this effect. A shift towards extensive systems would allow for greater capacity to react to changes, but the limitation constituted by the human factor (farm labour) makes this shift very difficult at the present time.

10.10. MAIN RESEARCH NEEDS

The decision-taking process for the mitigation of the effects of climate change will be a sequential process within an environment of uncertainties (IPCC 2001b) that are being quantified and reduced as research advances.

10.10.1. Simulation models as tools for evaluating impacts. Connection with high resolution regional climate models.

The methodology to be applied is currently being generated in the PRUDENCE research project within the V EU Framework Programme (PRUDENCE: *Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects*, EVK2-2001-00156).

10.10.2. Generation of impact maps and proposal of indicators for strategy design

Crop productivity is one of the most important indicators, as this integrates the effects of all the environmental factors to which the crops have been subjected through their growth and development. Productivity in relation to the area used (yield), in relation to ET (WUE), and in relation to the amount of irrigation water (IUE) are quantifiable and have represented technological changes down through the years.

The impact of climate change can be assessed with this type of indicator on maps representing the various types of soils and main crops or plantations, thus facilitating economic analysis.

10.10.3. Forecasts of changes in water consumption by dry farming and irrigation systems. Effects on the National Irrigation Programme and the National Hydrological Plan

As was explained in section 10.4.2, the application of the forecasts of variation in precipitation to the available water supply for crops, although feasible, is difficult. The availability of water for orchards, olive groves and vineyards is one of the vital themes for study, that can only be made in connection with the other sectors involved in this project. A fundamental step involves the establishment of water or ET needs of crops in future climates.

Greater knowledge of the response of crops to changes in CO_2 concentration, improved simulation of crops and of impacts, and the improvement of databases currently being developed, allow for the generation of impact maps that would establish the agricultural zones and trends of change.

These plans can be considered as future collective regulations for promoting the innovation necessary for adaptation, as presented in a generic fashion in IPCC (2001b).

10.10.4. strategies for the conservation of the resource base

Given the area of dry farming systems and of their low-productivity, their inclusion in impact assessment studies is recommended. Soil quality is directly related to capacity for water retention, the return of crop residues to the soil, the maintenance of cover in the plantations, mineralization rates of organic matter, etc., and all of these factors are affected by the management techniques adopted by the farmer.

The establishment of broad lines of action is being considered for the different crop systems, such as the "*Good Agricultural Practices*" by the FAO).

10.10.5. Effects of extreme years, forecasts and adaptations

An evaluation of the impact of extreme years using the previously described methodology, would serve as the basis for the economic analysis necessary for choosing suitable mitigation strategies in the context of sustainability, and equity (IPCC 2001 a and b) .

10.10.6. Animal response (intake and wellbeing) and capacity for adaptation to climate changes

The research needed to reliably predict the effects of climate change would involve establishing the effect of variations in temperature, humidity, etc., on ingestion capacity, and the parameters indicating animal wellbeing, and, consequently, learning of the effects on animal response and the quality of products obtained in these conditions. With this information and that available from previous experiences, dynamic models could be constructed, which have been described in section 10.8.3.

10.10.7. Economic evaluation of the effects of climate change on production

Economic evaluation of the effects on productivity and on the implementation of adaptive measures should be based on quantifiable indicators as proposed, not only by the agricultural sector, but also by others, such as water resources, edaphic resources, insurance sector, forestry sector.

This would enable a more complete study than a simple cost-benefit analysis, Recommended techniques are a multi-criteria analysis and compromise programming.

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11. IMPACTS ON COASTAL AREAS

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ABSTRACT

The main problems of climate change in coastal areas are related to potential changes in the frequency and/or intensity of storms, and to a possible rise in mean sea level (MSL). With regard to sea level, the estimates by the IPCC for the end of the century have been reduced as more reliable data has become available, from 50-90 cm (IPCC 1998) to 13-68 cm (IPCC 2001). The values by the INQUA (International Union for the Study of Quaternary, Sea-Level Change and Coastal Evolution Commission) and by the IGCP (International Geosciences Programme, Projects 369 and 437) are even more modest: 10-20 cm.

For the E and S coasts of Spain, the available data indicate a generalised tendency towards the stability or slight drop in MSL, although local subsidence could camouflage this effect (for example, the Ebro delta). This tendency is seen in coastal progradation, the growth of litoral spit bars, the infilling of estuaries and the disappearance of wetlands. To the contrary, for the N coast, that data indicate a tendency to rise, at rates of 3-4 mm/year in the second half of the 20th century. This is combined with observations that indicate a clear decrease in many confined beaches, retreat of dune fronts and "soft" cliffs or narrowing and/or breakage of litoral spit bars, which cannot exclusively be attributed to a reduction in sediment input, given the fact that recent data indicate, to the contrary, marked increases in sedimentation rates in estuaries throughout the last century.

Furthermore, different studies show that the MSL was almost 1 m above the present one between approximately 5,500 and 2,000 years ago, at times in which climatic conditions were similar to those expected for the end of this century.

Based on these data, it could be considered that a rise of around 50 cm for the end of the century is a reasonable scenario. A pessimistic hypothesis, much less likely but which cannot be ruled out, would involve a rise of 1 m, corresponding to the maximum in certain predictions and with the aforementioned levels in the past. This situation appears to be much less likely on the S and E coast than on the N.

In the case of a generalised rise in mean sea level (MSL), the most vulnerable areas would be deltas and naturally or artificially confined beaches. The part of the Spanish coast with cliffs made up of resistant rocks would present no particular problems. There is potential danger, however, regarding the stability of the coasts with cliffs consisting of non-coherent materials (not very significant). The hypothetical scenario of 0.5 m maximum possible rise could mean the disappearance of 30% of the beaches in the eastern part of the bay of Biscay, considering that no natural or artificial nourishment of sediments takes place. A relative rise in MSL by 0.5 m without an associated sediment response would give rise to the disappearance of around 50% of the Ebro delta.

These hypothetical rises in MSL could cause the flooding of coastal lowlands (deltas, coastal wetlands and agricultural and built up areas in the vicinity of deltas or on coastal alluvial plains). On the eastern part of the Bay of Biscay, this could imply the flooding of some of the lowlands, estimated at 23.5 km^2 for the above-mentioned value. In the Mediterranean and the Balearic Isles, and supposing a maximum of 0.5 m, the most threatened areas, apart from the aforementioned deltas (Ebro and Llobregat), are the Manga del Mar Menor (around 20 km), the Cabo de Gata lagoons (5 km) and, in the Gulf of Cadiz, around 10 km of the coast of Doñana and around 100 km^2 of marshland. Some of these areas are occupied by buildings or infrastructures, but others are devoted to agricultural use or are part of a nature park, and could allow for the formation of new wetlands which would compensate, by displacement, for the foreseeable loss of other wetland areas due to permanent flooding.

However, more precise estimates about the future evolution of this kind of coastal systems should also take into account changes in the height and intensity of waves and meteorological tides.

It should be pointed out that, added to the potential impacts of climate change, other factors of anthropic origin, such as changes in river sediment transport or construction on the coast, have, at least, a similar potential influence in the short-term stability of the coast.

As main prevention or adaptation strategies, immediate action is recommended in relation to human factors affecting the coast. Among these, we could highlight the maintenance of discharge and solid deposits by rivers as a solution to the “origin” of the problem (the lack of sedimentary matter). As a solution to the “symptoms” of the problem (retreat or excessive mobility of the coast), we could mention the stabilisation of beaches and dunes, the construction of structures aimed at limiting the transport capacity of the incoming waves and artificial sediment nourishment. In another category are actions for protecting natural values (strict land planning aimed at ensuring the maintenance and recovery of valuable areas). It is also considered necessary to delimit and make an inventory of the areas and elements that could be affected by a rise in sea level, meteorological tides and changes in direction, height and frequency of swell, in order to define where to apply abandonment and retreat strategies, or ones aimed at protection. In any case, acting upon these factors will contribute to attenuating the future impacts of climate change, regardless of the uncertainties related to the magnitude thereof.

11.1. INTRODUCTION

The coastal area constitutes the interphase between the atmosphere, the hydrosphere and the lithosphere, which makes it particularly sensitive to climate changes. The status of interphase gives the littoral great diversity with regard to environments and resources, and makes it a particularly attractive area for human settlement, both for residence and because of the great variety of productive activities that can be established therein. The result is that around 60% of the population is concentrated on the coast, most of this quite close to the coastline (Nicholls and Branson 1998).

11.1.1. Types of coasts

Within the littoral, the vulnerability of the coastal area to the potential impacts of climate change depends on the characteristics of the sectors or large “environmental units” it consists of. In this analysis, the following large types of coastline have been distinguished:

Coastal lowlands associated with river mouths

In which the interaction between human activity and/or changes affecting the ocean or river flows and natural systems could give rise to particular problems.

Estuaries, bays and rías. Embayments of very different dimensions. They are usually flanked, at least in part, by coastal lowlands with wetlands, tidal flats and beaches at the estuary mouth and also inland. These are the areas with the greatest potential impact, both due to their characteristics and to the settlements they contain.

Deltas. Protuberances formed at the mouth of water courses where the sediment input exceeds the redistributing capacity of sea currents and waves. They do not exist on the North coast, due to the predominant geomorphological and climatic features.

Wetlands (marshlands) and coastal lagoons.

Areas of coastal lowlands, not associated with estuaries or deltas, usually separated from the sea by systems of litoral spit bars or beach barriers and which can present marshland vegetation, can be found along the whole Spanish coastline.

Beaches.

Confined beaches: limited at the upper part by a) cliffs or artificial structures, restricting or preventing migration inland or b) at their sides by natural structures (capes) or artificial ones (groins) limiting longitudinal dynamics.

Unconfined beaches: such as litoral spit bars or beach barriers made of sand adjacent to coastal lowlands, with possibilities for displacement inland. When the sediment volume and wind climate allow, they are associated with aeolian dune fields.

Both typologies occur along all sectors of the Spanish coastline.

Cliffs.

“Hard” cliffs. Comprising compact rocks, resistant to erosion. These areas do not present significant problems in this sense, and will consequently not be analysed.

“Soft” cliffs”: Comprising materials that are not very coherent, easily eroded and that currently present annual coastal retreat rates measured in decimetres to tens of metres or higher.

The former type predominates on the North and Northwest coasts, in the South and in certain parts of the Spanish Mediterranean. The latter abound in the Southwest of the Peninsula and in parts of the Levant.

Ports.

Rigid areas protected by vertical or sloped groins or jetties, which would require a re-evaluation of their structural reliability in relation to possible local climate change.

11.1.2. Relative distribution

The Mediterranean coast is made up of a succession of stretches with cliffs (usually “hard” ones) and coastal lowlands, in which torrential, wadi-like rivers called by locals “ramblas” or “rieras” flow, some of these forming deltas. The biggest delta is the Ebro. On the coast of Valencia, there are abundant fan deltas of the rivers Mijares, Palancia and Belcaire, which cause coastal progradation. On the South coast, into which flow big ramblas, deltas have also formed, some of the main ones being the Andarax and Adra deltas (Almería) and that of the River Vélez (Málaga).

In the lowlands there are wetlands (marshlands) and coastal lagoons, of varying sizes, separated from the sea by spits accumulated due to coastal drift. In some cases, one can find wetlands and lagoons associated with the deltas. In general these are highly populated areas, with highly-developed tourism, maintained practically throughout the whole year, and which also present a high ecological value.

The South Atlantic coast (Gulf of Cádiz) and particularly the coast of Huelva, is formed by cliffs comprising mainly soft materials, interrupted by river mouths constituting estuaries that are practically silted up. All of these include systems of sandy spits formed in favour of a general drift in the E-SE direction, which enclose, landwards, marshland systems, the biggest of which is that of the river Guadalquivir, which contains the Doñana National Park. There are also big bays, the largest of which are those of Cádiz and Algeciras.

In the Canary Isles, there is a clear predominance of “hard” cliffs, and the beaches tend to be quite short (many of them are stony), and large ones are usually only found in the S of Gran Canaria and in Fuerteventura.

In Galicia and the Bay of Biscay the coast mostly comprises cliffs, with a high proportion of “hard” cliffs. On the west coast of Galicia, the predominant elements are rías, whereas in the Bay of Biscay, there are many bays or rías, with large intertidal areas and marshlands in the vicinity. Most of the main towns and cities in this area are located by bays or estuaries.

11.1.3. Values and problems

The main values of the coastal area include the peculiarity and scarcity of certain units of great ecological interest (dunes, marshes and intertidal areas, some cliffs), and other resources that serve as a base for important economic sectors, in particular the landscape and the beaches, which are the mainstay of the tourism and recreation sector.

The problems considered with regard to the preservation and sustainable use of the aforementioned resources lie in the pressure applied upon them by the different activities involved therein, which, furthermore, often enter into mutual conflict.

Thus, the extent and state of several units of high value for conservation have become very deteriorated as a result of the pressure applied by housing development (related to a great extent to tourism), especially, but not only, on the Mediterranean coast, the Gulf of Cadiz and the Archipelagos. There are also evident pollution problems affecting some of these environments, particularly *albuferas* (lagoons), marshlands and intertidal areas, as a consequence of agricultural, industrial or residential activity (for example, the *albufera de Valencia*, Mar Menor, vicinity of Doñana national park, estuaries in Cantabria, etc.).

In some cases (Almeria, Cantabria), the aeolian dune fields have been totally eliminated by sand mining and in many other cases they have been destroyed by building directly upon them. The elimination of the exchange role played by dunes and beaches, along with the regulation of river basins, which has clearly reduced sediment supply, and the construction of different coastal infrastructures, are the main causes of the instability of unconsolidated coastlines (beaches, deltas), particularly in the Mediterranean.

Artificial desiccation and fill of marshlands and intertidal areas for various uses were the main factor of degradation of these important units throughout the last century, especially on the coast of the Bay of Biscay. Fortunately, in recent years, certain actions aimed at inverting this process have been implemented.

The overexploitation of aquifers and the resulting saline intrusion constitutes another problem affecting many sectors of the E and S coasts.

Lastly, we should point out the serious deterioration of landscape quality (a resource of great importance, both for the tourism sector and for the population's own quality of life), which has occurred as a consequence of building along the coast, a process which is particularly evident on the Mediterranean coasts, in the Gulf of Cadiz and the Archipelagos.

In general terms, land-use planning (distribution of uses and activities) together with the construction of infrastructures, impose rigidity upon the coastline which needs to be made compatible with the inherently dynamic nature of the land-sea interphase.

The problems indicated also represent the main threats for the coastline in the near and mid-term future, and it is in this context that we ought to consider the possible impacts of climate change, in order to assess the importance of these in comparison with the former ones.

11.2. SENSITIVITY TO THE PRESENT CLIMATE

11.2.1. Present climate. State of reference

The present climate in the Galicia-Bay of Biscay area is characterised (averages for the 1971-2000 period) by mild temperatures with annual averages ranging from 13.2º C (San Sebastián-Igueldo) to 14.8º C (Pontevedra), averages of from 16.2º C (Igueldo) to 19.1º C (Pontevedra) and averages of minimums from 9.4º C (Bilbao-Sondica) to 11.4º C (Coruña). Annual rainfall ranges from 971 mm (Gijón) to 1909 mm (Vigo).

The Atlantic coast of the Gulf of Cadiz has a Mediterranean-type climate with Atlantic influence and mean annual temperatures of around 17-19º C, with summertime maximums of between 35º and 40º C. Average annual rainfall is below 600 mm, with two maximums (November-December and springtime).

The current climate of the South and Southeast of the Mediterranean coast is semiarid with average temperatures in summer (July) increasing from the coast of Valencia (24.6ºC) to the coast of Malaga (25.6ºC), decreasing once again towards Gibraltar (24.4ºC) due to the proximity of the Atlantic. The annual averages for winter (January) maintain the same tendencies: Valencia (10.3ºC), Malaga (12.5ºC) and Gibraltar (12.4ºC). On the Balearic Isles, mean annual temperature is around 17º C, with wintertime averages of 10º C and summertime ones of 24.5º C.

In the Mediterranean, the minimum annual mean rainfall (200-300 mm) is recorded on the coasts of Alicante and Almeria, and the highest averages (500-750 mm) on the Valencia and Malaga coasts. On the Balearic Isles, average rainfall is around 500 mm and is concentrated between September and May. A peculiar feature is the appearance of abnormal deviations of rainfall values, with downpours that discharge a large amount of water in very few hours, sometimes one third or a half of mean annual rainfall.

Winds and waves/swell

The prevailing winds have a great influence upon the direction of the incoming waves and therefore upon coastal currents and the associated transport of sediment. On the coast of Catalonia, the prevailing winds and swells are easterly (more energetic storm swell, on having a greater area of generation), southerly, (commonly known as "Garbo") and northerly ("Tramontana") to north-westerly ("Mestral"). The annual mean significant wave height is below, although close to, 1.0 m and the storms can give rise to maximum significant wave heights of close to 6.0 m, with individual waves of up to 10.0 m (Gómez *et al*. 2001). On the Alicante coast and in eastern Murcia, the most influential winds are the "Levante" (easterly) and the south-easterly winds, although we must also take into account the westerly and north-westerly ("Mistral") winds. Of great importance towards the South, is one of the most characteristic winds of the western Mediterranean: the "Sirocco" or "*lebeche",* a south-westerly wind which is very hot in summer and of moderate temperature in winter and which, between *La Nao* Cape (Alicante) and *Gata* Cape (Almeria), gives rise to dust storms that deposit a red sediment known as "Saharan dust" that clearly affects the life cycles of the flora and fauna of the coastal wetlands. Of great relevance between Almeria and Malaga are the south-westerly winds associated with winter storms. They are usually accompanied by rains and cause over-elevation of local sea level, which favours coastal erosion.

In the Gulf of Cadiz, the prevailing winds blow from the SW, causing a general littoral drift towards the E on the coast of Huelva, where it contributes very much to the formation of sand bars which create big spit bars. Southeasterly and easterly winds are also important, due to the role they play in the processes of coastal erosion associated with storms.

In the Balearic isles, and depending on the orientation of the coast, the most influential winds are those from the North ("Tramontana"), the Southwest and the Southeast. These winds accumulate dune fields and cause more or less permanent littoral drifts that favour the growth of spit bars in the Alcudia and the old Palma lagoons, now silted up. The storms associated with southerly winds can pile up waves over 5 m high to the South of Majorca.

In Galicia and the Bay of Biscay coast, the prevailing winds affecting the stability of the coast are from the NW, and the associated storms cause swell of great height which frequently give rise to erosion of the beaches, and even the breakage of some sand spits. On the confined beaches of this coast, a notable loss of sand can often be observed, caused by storms from the NW, which tends to recover with a change in conditions. Indeed, there are numerous cases of this kind of beaches disappearing or being seriously reduced in the winter, and returning in the spring-summer, with the reduction of these storms. On the coast of the Rías Bajas there are also big storms associated with winds from the SW.

Tides

On the Galicia-Bay of Biscay coast, the tidal ranges vary from somewhat less than 1.5 m in neap tides and over 4 m in spring tides, and these level differences can be accentuated in the event of over-elevation due to meteorological effects (storms from the NW, low pressure).

The Gulf of Cadiz is mesotidal, with a mean astronomic tidal range of 2 m (Dabrio *et al*. 1980).

The Mediterranean coast is microtidal and the astronomic component is around 8-10 cm but, combined with the daily breeze, it can raise the mean level by around 30 cm in good weather (Dabrio and Polo 1987).

During storms and prolonged wind events involving the *Levante* and *Poniente* winds, the over-elevation caused by the meteorological tide can exceed one metre on the coastal segments oriented towards them. The return period of these exceptional events can vary from ten years for an over-elevation of 1 m to 100 years for 1.5 m (Sánchez Arcilla and Jiménez 1994).

11.2.2. Effects of climatic variability on the coast, based on their past evolution

The change tendencies established for the Cantabria area during the Holocene (Figure 11.1); according to Menéndez Amor 1961a,b,c, 1963; Menéndez Amor and Florchutz 1961, 1963, 1964; Mary 1968, 1973, 1975, 1979, 1985, 1992; Mary *et al*. 1975; Mariscal 1983, 1986, 1987; Peñalba 1989; Cearreta *et al*. 1990; Salas 1993; González *et al*. 1996 1999), indicate that around 5500 BP a relative temperature maximum was reached, accompanied by a decrease in mean annual rainfall. In the early centuries of our Era, there was a new episode of relative warming, followed by a cooling phase that ended in the Little Ice Age, after which the warming tendency started, and continues at present. Projections by the available models suggest that similar conditions to those “climate maximums” of the Holocene could be reached during this century.

Although the available data on fluctuations in sea level in these times are not very conclusive, as they present certain apparent contradictions among the different areas (Table 11.1), in the Cantabrian Holocene there are evidences of transgressive phases, according to what has been observed in numerous analyses (palinology, anthracology, palaeontology, archaeology, morphology, sedimentology, etc.) carried out by different authors in emerged coastal deposits and in estuarine infills (Altuna *et al*. 1989; Cearreta 1992, 1993, 1994, 1998; Cearreta and Murray 1996; Edeso 1990, 1994; Flor 1983, 1995; Hoyos Gómez 1987; Mary 1968; 1975, 1979, 1985; Mary *et al*. 1975; Moñino 1986; Moñino *et al*. 1988; Mosquera *et al*. 1994; Rodríguez Asensio and Flor 1980; Rivas and Cendrero 1987; Santos Fidalgo *et al*. 1993; Santos Fidalgo and Vidal Romaní 1993a, Vidal Romaní *et al*. 1997). The first marine incursion corresponds to the Flandrian transgression, which has been clearly identified and dated in other parts of Europe. At this time, sea level could have reached elevations of between 1 and 3 m above the present level (according to different authors). The marine transgression after the start of the Christian era appears to have been of lesser magnitude.

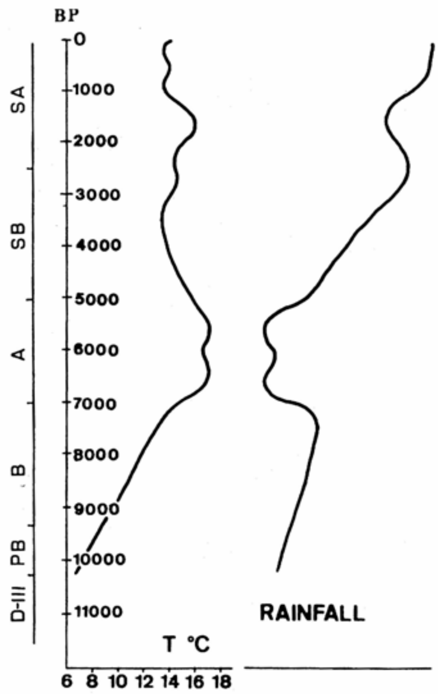

Fig. 11.1. *Change tendencies established for the Cantabrian area during the Holcene (González et al. 1996)*

Table 11.1. *Dated Holocene coastal deposits around the Bay of Biscay. Note: the elevations indicate the position of the deposits in relation to the current intertidal mean level, and not the sea level at the date on which this was indicated*

Sample	Situation	Site	Age BP	Height	Author
Plant remains	Estuary IS 1	Bidasoa river	7810±130	- 25 m	Cearreta *et al*. 1992
Plant remains	Estuary IS 2	Bidasoa river	6590±120	-15.5 m	Cearreta *et al*. 1992
Plant remains	Estuary IS 2	Bidasoa river	6630±120	- 2 m	Cearreta *et al*. 1992
Peat	Beach	Gerra I	5880±130	Intertidal	Mary 1979
Tree trunk	Beach	Gerra IIIa	5850±200	Intertidal	Mary 1979
Organic matter	Estuary	HerrikoBarra	5810±170	Intertidal	Cearreta *et al*. 1990
Peat	Beach	Gerra II	5300±120	Intertidal	Mary 1979
Tree trunk	Beach	Gerra IIIb	5250±90	Intertidal	Mary 1979
Organic matter	Estuary	HerrikoBarra	4920±100	+ 2.5 m	Altuna *et al*. 1990
Peat	Beach	Bederna stream	4770±110	Intertidal	Mary 1979
Peat	Beach	Ares	4350±90	Intertidal	Santos-Vidal, 1993
Tree trunk	Beach	Trengandín	4070±100	Intertidal	Cearrera 1993
Peat	Beach	Ares	3970±50	Intertidal	Santos-Vidal, 1993
Wood	Beach	Ares	3450±100	Intertidal	Santos-Vidal, 1993
Wood	Beach	Trengandín	3080±100	Intertidal	Cearrera 1993
Tree trunk	Beach	Trengandín	2890±70	Intertidal	Salas *et al*. 1996
Wood	Fluvial	Besaya river	2780±80	- 0.5 m	Salas *et al*. 1996
Plant remains	Estuary IS 2	Bidasoa river	2740±90	- 5 m	Cearreta *et al*. 1992
Vegetal carbon	Estuary	Xivares	2150±110	+ 1 m	Mary 1968
	Marine terrace	Fontías	1920±120	+ 1 m	Mary 1975

On the coast of the Gulf of Cadiz, the pollen sequences from the records found in cores in coastal and estuary lagoons (Zazo *et al*. 1996, Yll *et al*. 2003), show no appreciable temperature changes during the mid- and recent Holocene, but they do show a tendency towards aridity after ca. 5000 BP (Zazo *et al*. 1999). This general tendency was interrupted by short episodes (at a scale of hundreds of years) of greater aridity between 2700-2400 BP and 900-800 BP (Borja *et al*. 1999).

With regard to variations in sea level, studies of estuary fills (Dabrio *et al*. 2000) and of litoral spit bar systems (Zazo *et al*. 1994, Goy *et al*. 1996, Zazo *et al*. 1996) suggest that, once the Holocene maximum was reached (ca. 7000 cal BP), the general tendency was towards a drop in MSL, interrupted by short intervals of relative rises, of a magnitude of less than one metre around 2700 BP and 500 BP.

Rodríguez Ramírez *et al*., (2000) studied the litoral spit bar systems in the Gulf of Cadiz, and observed that the coastal progradation continues, and that in the last four decades (1956-1996) five new beach ridges have been formed.

On the Mediterranean coast, the pollen analyses from cores drilled in river mouths on the Almeria coast (Yll *et al*. 1994, Pantaleón-Cano *et al*. 1996, Jalut *et al*. 2000) record a radical change in plant cover that indicates a change from humid conditions to arid ones in ca. 5400 cal BP. The tendency towards aridity has lasted to the present, although it was interrupted several times by periods of extreme aridity of secular duration at around 4200 cal BP, 2700 cal BP and 1900 cal BP (Goy *et al*. 2003).

The litoral spit bar systems of Almeria provide data on the changes in relative sea level. There is a general tendency towards relative drop in MSL , which allows for the maintenance of progradation on the coastal plain, but several episodes of a relative rise in MSL of secular duration were detected. The magnitude of these rises, recorded in 5400 cal BP, 3100 cal BP, 1900 cal BP and 500 cal BP, is less than one metre.

Fernández Salas *et al*. (2003) studied the prodelta of the river Guadalhorce (Malaga), deducing that the deposit of sedimentary units subsequent to the trangressive maximum (ca. 7000 BP) is controlled by eustatic changes that present two small-range cycles (few metres) and a periodicity of around 3,000 years. Within one cycle, the greatest duration corresponds to the progradation period (drop in MSL) when there is more sediment input to the coast, whilst the periods of relative rise in MSL are usually shorter, with a very marked one around ca. 3000 BP.

In the Ebro delta, a markedly subsiding area, Somoza *et al*. (1998) described the eustatic oscillations for the last 7,000 years. More recent indirect estimates of subsidence rates range from 1.0 mm/year to 5.00 mm/year (Sánchez-Arcilla *et al*. 1998). The range of the estimates varies with the type of methodology used to obtain them (sediment balance, topographic levelling/survey, old levees) and with the thickness and age of the delta area considered.

In the Balearic Isles (Burjachs *et al*. 1994), the pollen analyses from core drills to the North of the Albufera de Alcudia (Majorca) record humid conditions during the Holocene climatic optimum (7100-6000 BP), with abundant sediment input to the coast. After 6000 BP there is evidence of a change towards aridity which is accentuated around 2400 BP. The Holocene marine terraces and the litoral spit bar systems in the bays of Alcudia and El Prat (Majorca) also record the relative drop in MSL after 7000 BP (Goy *et al*. 1997), within a tendency interrupted by short episodes of relative elevation around 4400 BP, 3000 BP, 1800 BP and 500 BP.

11.2.3. Present coast. State of reference

The sedimentary coastal response to the climate changes predicted for the future should be analysed from the perspective of the present situation and the evolution of this in the past. If a state of reference is not established no comparison will be possible.

The past evolutionary history reveals a general tendency towards progradation on the South-Atlantic coast, recorded in the litoral spit bar systems (figura 11.27: H units by Zazo *et al*. 1994 and Dabrio *et al*. 1996) integrated by a certain number of small ridges and swales. The study of the evolution of these litoral spit bar systems in the last few decades (Rodríguez Ramírez *et al*. 2000) suggests a continuous tendency towards progradation.

Likewise, the tidal flats, which tend to disappear, reached in their natural state a maximum development around 2400 BP (Dabrio et el. 2000), due to the increase in the rates of coastal progradation and vertical accretion of the sedimentary units inside the estuaries.

Furthermore, part of the Gulf of Cadiz coast is currently undergoing an accelerated process of erosion (figure 11.2). Clear evidence of this are the watch towers along the coast, the construction of which dates from the 16th century to the start of the 17th, the bunkers from the 30s, and the tangible retreat of the soft cliffs in El Asperillo (Huelva), Sanlúcar de Barrameda, Chipiona and other parts of the Bay of Cadiz in the last quarter century (figure 11.3). Recent research along the whole coast of Cadiz, based on aerial photography and continuos monitoring of beach profiles in 34 stations (Del Río *et al*. 2002) revealed that the two main causes of coastal erosion involve human intervention: river dams that reduce sediment supply to the coast, and coastal structures (dikes, groins, ports and other constructions) which alter littoral dynamics.

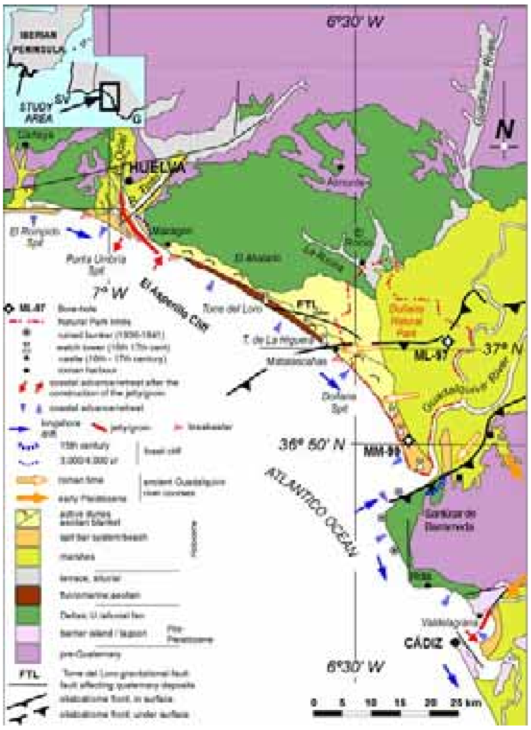

Fig. 11.2. *Present erosion conditions along the coast of Cadiz (Zazo et al. 1987, mod.)*

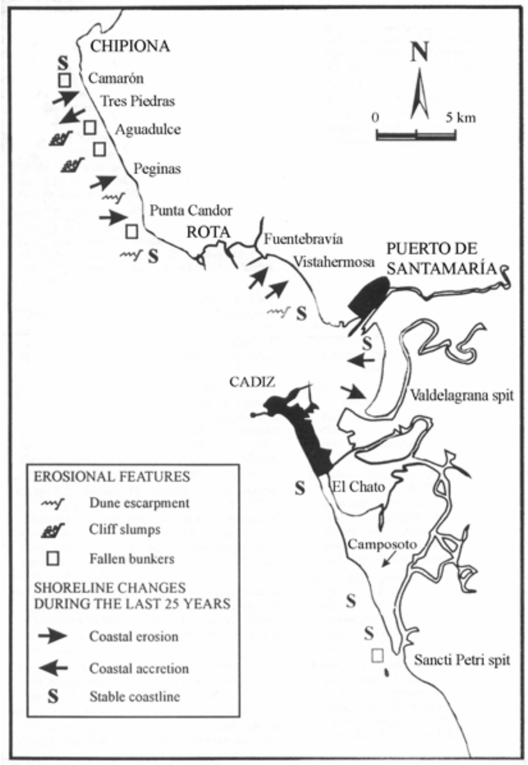

Fig. 11.3. *Retreat of soft cliffs in the Bay of Cadiz (Del Río et. al. 2002)*

In the Mediterranean area, erosion has greatly increased as a consequence of the drastic reduction of fluvial sediment input due to the regulation and reforestation of river basins and the construction of dams. The coastal evolution of the Ebro delta clearly shows this tendency (Sánchez-Arcilla *et al*. 1998). Most of the areas affected by accelerated erosion are the result of the construction of ports that interrupt littoral drift, and the situation is exacerbated by urban development and the construction of infrastructures as well as by the associated coastal defence structures. In some cases, this has involved the erosion of the barriers separating coastal wetlands from the sea, such as the one between Puçol and Massalfasar, as a result of the port of Sagunto, the spit of the lagoon between Valencia and Cullera, due to the Valencia port, and the closing barrier of Santa Pola lagoon, a consequence of the Santa Pola port (Alicante). In other cases, the erosion of beaches and coastal plains has been radically accelerated, like in Puerto de Mazarrón (Murcia) and Carboneras (Almeria).

The conatruction of walls or coatings in areas where retreat is now an established fact (for example, in the Manga del Mar Menor) breaks the natural summer/winter sediment balance and causes two negative effects: it inhibits the growth of the beach in summer by waterproofing the swash area, and prevents the erosion of the upper part of the beach in winter, and consequently, the formation of the sediment bar which acts as a reserve in the area of transition to the shoreface. In all these cases, the estimate of transports, both longitudinal and transversal, presents multiple uncertainties with regard to the present climate (Sánchez-Arcilla *et al*. 2001), and even more for future climate scenarios.

On the northern coasts, the situation is different, as the basins flowing to these have not generally been subjected to any great regulation. On these coasts, there is evidence of appreciable increases in sediment deposits in recent times, most likely as a result of human intervention (Cendrero 2003; Remondo *et al*. 2004; Méndez *et al*. 2004, Cendrero *et al*. 2004).

The retreat of beaches and dune fronts, however, is perceptible in many places, or even the accelerated erosion of "soft" cliffs (Rivas 1991; Rivas and Cendrero 1991, 1992, 1995).

11.2.4. Spatial scales

In order to analyse possible future change, it is necessary to combine the spatial and temporal scales at which the morphodynamic processes are acting. The definition of these scales must be based on the available knowledge of the driving mechanisms and coastal response observed. The main problem lies in the fact that an agent (for instance, swell) acts at different scales and in different ways. At the main scale of the considered process, the agent will be a "controller" whereas at other scales, it will play the role of "noise" or boundary condition (de Vriend 1991). As a matter of illustration, let's consider the longitudinal transport of sediments induced by the swell on the coast of the Ebro delta (Figure 11.4). The "natural" scale of the longitudinal transport is medium-term, that is, a few years. If this scale coincides with the study period, longitudinal transport will be the main component of this study and the role it plays is illustrated in figure 11.4b, which shows how annual net transport rates account for the corresponding sediment balance. This also means that the long-term volumetric changes will be controlled mainly by the net longitudinal transport pattern.

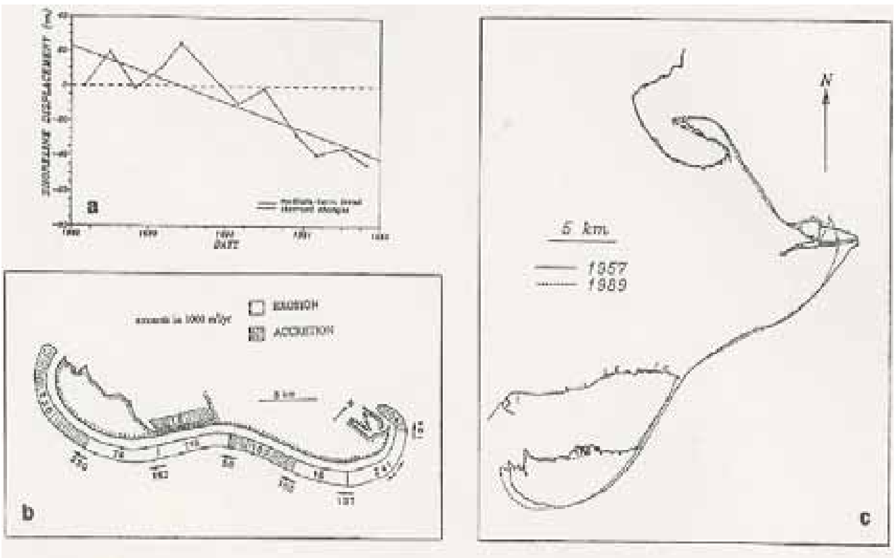

Fig. 11.4. *Role played by sediment transport along the coast according to different time scales: (a) short-term, (b) medium-term and (c) long-term (adaptaded from Jiménez and Sánchez-Arcilla 1993).*

When the study period is smaller than the temporal scale of the process, this will act as a boundary condition as indicated in figure 11.4, in which the movements of a coastal profile in the Ebro delta appear "against" the medium-term tendency. The classical seasonal variations in the transversal behaviour of the strandline can be observed. The mean tendency shown in this figure is associated with the positive gradient in longitudinal net transport average, which gives rise to erosive behaviour and therefore represents an external boundary condition

Finally, when the time scale of the study is greater than that of the process considered, this will have a residual or "noise" effect. Figure 11.4 illustrates this fact. The long-term evolution of the coast of the Ebro delta presents a reshaping that could be defined in terms of the corresponding sediment balance. Longitudinal sediment transport cannot be considered responsible for this balance, as the system is almost “closed”, at least for the sand fraction (Jiménez *et al*. 1993). The observed reshaping , however, is due to net longitudinal transport, and these processes at this long-term scale will therefore have a residual effect as a reshaper but will not contribute to sediment balance at this scale.

Coastal response depends on the climatology, geomorphology and structures existing in each coastal sector and it has multiple scales. For analysis of the coastal response to a possible climate change at local range, three scales are usually considered:

1. Long-term scale, which is the one most directly related to changes at global scale (area, profile and sedimentary balance) and which is controlled by agents such as: sediment input from rivers, changes in relative land-sea level, sediment transport at the internal limit of the platform, sediment exchanges between the strandline, coastal strip and the adjacent land (due, for instance, to wind transport) and variations in climatic factors at decadal scales. The residual effect of longitudinal sediment transport can also be considered as an agent.

2. Medium-term scale, which is associated with systematic coastal changes in the order of kilometres and with temporal variability in the order of years. The main coastal response that can be observed at this scale is the remodelling of the coast and the main controlling factor involves net sediment transport (longitudinal and transversal). The changes in the coast are the result of integrating the different swells acting upon a coastline, although the way of averaging those, is far from being universally accepted.

3. Episodic scale, which is associated with the actions of extreme driving mechanisms that act for a limited number of days and have an approximate return period of decades. These agents cause great changes of impulsive type in the coastal area, and in the case of our Mediterranean coast, two of them are essentially considered: a) the action of storms simultaneously characterised by meteorological tides and high-energy waves (which will cause accentuated erosion and the eventual breakage of the more fragile coastal sections) and b) extreme floods providing a big sediment supply over a short period of time and, simultaneously, the intense re-shaping of the area close to the river mouths. These extreme events are characterised by an immediate coastal response, through which the coastal section affected will subsequently recover at a different temporal scale, which can be considered as medium-term. Possible climate change will undoubtedly affect the distribution of these extreme events. Its study is therefore particularly important in order to characterise the impact of climate change upon our coasts.

The coastal response observed in each case will depend on the time scale chosen for the study. The vulnerability of the different types of coastal responses to climate change will depend, as has already been mentioned, on the existing geomorphology, climatology and structures. In this sense, coasts with cliffs will be less vulnerable and less dynamic, whereas the sedimentary coasts with a limited granular volume will be the most vulnerable ones. Sedimentary coasts with an “undefined” volume of material, although they may be susceptible to big changes caused by the impact of climatology, will present less vulnerability. The two types of coasts that are in a more fragile balance (due to being the result of the balance between land, sea and atmospheric factors) and are therefore more vulnerable to possible local climate changes, are deltas and estuaries, which will be dealt with in detail in this chapter.

11.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

The factors shaping coastal areas are related, on one hand, to processes taking place in river basins and, on the other, with marine dynamics. Among the former are those affecting the generation and transport of sediments towards the coast (changes in land cover and land use, construction of reservoirs, changes in rainfall regime, etc.). Among the latter, we can highlight changes in mean sea level and the intensity, frequency and prevailing direction of winds and swells. All of these influence the balance between erosion and sedimentation, but also the area and condition of wetlands and the erosion rates of the cliffs.

The impacts of climate change themselves (changes in temperature, rainfall, tendency towards humidity or aridity, changes in sea level, etc.) do not appear to be specific to coastal areas, except, naturally, with regard to the interaction between the atmosphere, the ocean and the coast, and the consequences for the related activities. For example, a temperature increase by a few degrees and a decrease in rainfall could have a positive impact on the North and Northwest coasts, due to the resulting greater climatic comfort and attraction for tourism, but there would be the opposite effect on the East coast, exacerbated by the *torrentialisation* of the water courses and the subsequent destabilisation of coastal dynamics.

An essential aspect of the study of driving factors involves determining their possible variation in time and even their recurrence and, in this case, the periodicity with which the events occur. This could be attempted with the use of drill-cores in ice, sea bed, lagoons and coastal or inland wetlands, high-resolution seismic studies on the continental platform and morpho-sedimentary analyses of coastal units, all of this backed up by radiometric dating. This is vital in order to distinguish between natural climate change, which obviously fluctuates, and that caused by human action.

The present situation and the change tendencies observed in the recent past, together with the projections made by climate models (see chapter on “The climate of Spain: past, present and future climate scenarios for the 21st century”), suggest that in the last third of this century, we may encounter mean and maximum temperatures that exceed current ones by between 2 and 3 degrees on the N coast and by 4 and 5 degrees on the E and S coasts. Seasonal rainfall will increase in the N and NW, with slight increases in the rainfall accumulated in autumn-winter and more evident decreases in spring-summer. In the south and East, to the contrary, decreases in rainfall are to be expected in all seasons (although not very marked ones). No significant differences have been indicated with regard to changes in the intensity, frequency and direction of winds.

We therefore find a scenario in which the magnitude of the changes to be expected in comparison to the present situation of the climatic variables affecting swells, tides, water and sediment input, and therefore, the stability of the coast (fundamentally of the beaches) has to be added to the effects that human action has previously had and can have on these processes.

11.3.1. Mean sea level

The term “mean sea level” indicates a theoretical situation and refers to a point on the coast considered to be fixed and stable. In Spain, this point is officially set in Alicante. On speaking of “mean level”, a certain vertical variability is accepted, which is considered as “normal” and which takes into account certain periodic oscillations longer than the long-term waves present on the coast.

Three components are usually considered in these oscillations:

1. The periodic component associated with the astronomic tide
2. The non-periodic component associated with the meteorological tide
3. A slower variation component associated with the relative variation in land-sea levels

The astronomic component plays a vital role on the mesotidal and macrotidal Atlantic coasts of Spain, but on the Mediterranean microtidal coast, they have very little effect, because their range does not usually exceed 25-30 cm.

The meteorological tide is caused by the combined effect of atmospheric pressure (inverted barometric effect) and the tangential pressure of the wind. Over-elevations of around 1 m have a return period of about 10 years, whereas those of 1.5 m have a return period of approximately 100 years. If we add a possible rise in MSL related to climate change, the return periods of the big over-elevations are clearly reduced: for a rise of 0.46 m, the return period of the 1.5 m high waves is reduced from 100 years to 9 years in the Ebro delta. To the contrary, the coasts with the highest tide ranges are less exposed to these effects.

The third component is related to the land-sea relative level and refers to the superposition of the eustatic variation (the change in MSL) and vertical local displacements of the substrate. This relationship is what enables the coastline to be shaped. This component is usually calculated with the use of data from tide registers and reflects the combined effect of the eustatic level and the local change in the land base on which the register is located (Emery and Ausbry 1991; Pirazzoli 1991). This means that much care must be taken in the extrapolation of the values to nearby coasts, in particular to the delta areas in which local subsidence (sinking) exceeds the eustatic component, as was documented by Suanez (1997) and Morhange (1994) who compared data from Marseilles (elevation 1mm/year) and from the Ródano delta (3 mm/year). In the Ebro delta, the rise is estimated at between 2 and 5 mm per year (Smith *et al*. 2000).

In relation to relative sea level, there has been a general tendency towards a drop since 5,300 cal BP. These are centimetric variations related to the greater or lesser entry of surface water from the Atlantic into the Mediterranean, reinforced by the winds and probably by the NAO (North Atlantic Oscillation). The litoral spit bar systems are constituted by beach ridges and swales, the generation period of which is related to the sunspot cycle (Zazo *et al.* 1994; Goy *et al.* 2003).

On the Atlantic coasts (Gulf of Cadiz), coastal progradation is represented by the development of litoral spit bars, and the start of estuary filling (Zazo *et al.* 1994, Goy *et al.* 1996), Dabrio *et al. 2000,* Lario *et al.* 2002) occurs from de ca. 2700 BP, indicating a general tendency towards a drop in sea level from that time up to the present. The most recent data (Rodríguez-Ramirez *et al.* 2003), covering the last 4 decades (1956-1996), indicate a close relationship between the periodicity of the SW winds, the number of storms and the formation of the ”mini beach ridges” that constitute Doñana’s spit bar system.

Existing data on variations in sea level on the North coast (Gómez Gallego 1994) during the last century indicate that between 1972 and 1990 there could have been a rise of 6-7 cm, (figure 11.5), although these values present some uncertainty.

With regard to the fluctuations in sea level in previous periods, the available data are not very conclusive, as they present certain contradictions. Table 11.1 summarises the existing data for sea levels in the Bay of Biscay. Figure 11.6 presents an approximate reconstruction of the variation in sea level during the Holocene, based on existing data on the N coast of Spain.

In accordance with the previously presented set of historic data, a rise in sea level of more than 1 m can be considered as a maximum hardly to reach in this century. Recent projections consider a set of much lower values (figure 11.7).

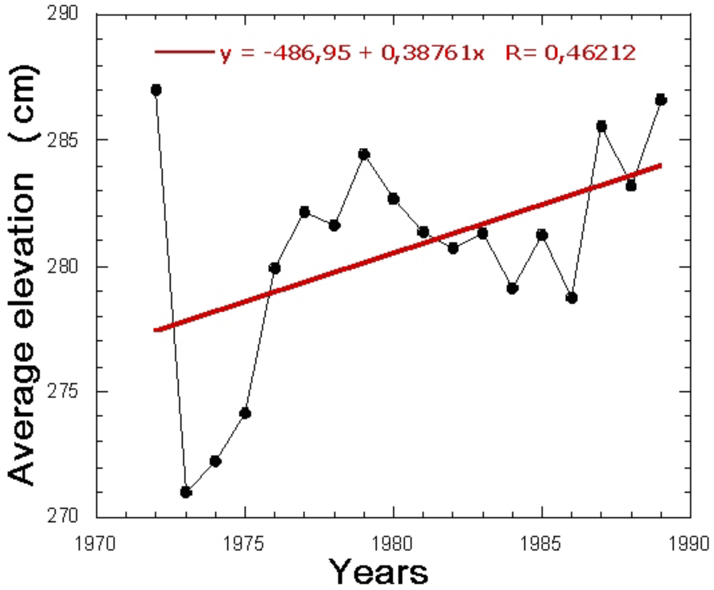

Fig. 11.5. *Variation in sea level based on the Santander Port tide register (Gómez Gallego 1994)*

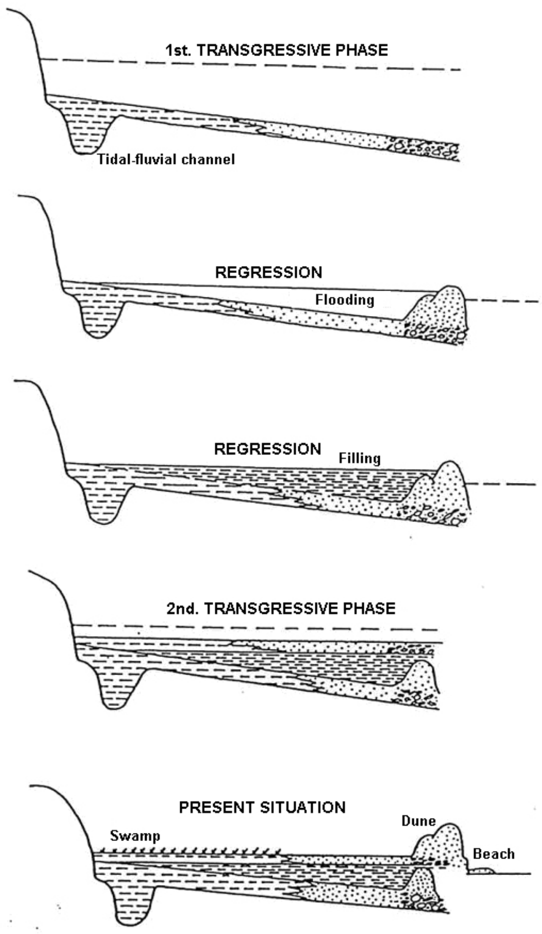

Fig. 11.6. *Reconstruction of the variation in sea level during the Holocene, estimated using existing data on the N coast of Spain. (Edeso 1994)*

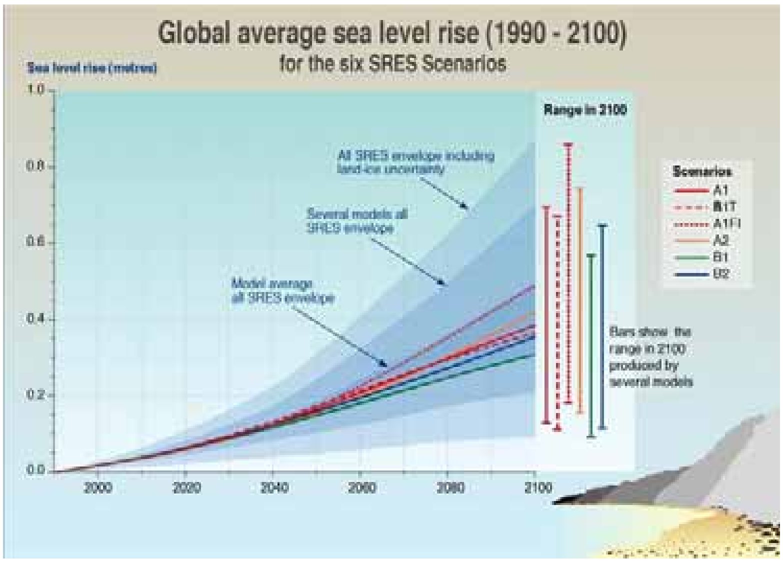

Fig. 11.7. *Recent projections under different scenarios of a rise in MSL (source: IPPC)*

11.3.2. Swell

Swell is one of the most important factors shaping the coast at the different scales considered. The swell climate is obtained from records, visual observations and numerically obtained data, and provides characteristic values of the wave height, period and direction. Wave height partly characterises transversal transport, which varies with the height of the wave to the power of between 2 and 5, which requires the correct determination of the probabilistic distribution of this variable. The longitudinal current generated and the corresponding transport depend upon the second and third variables.

In the *long term,* an essential component of the swell climate is the transport in the border area between the continental platform and the active coastal area (Wright 1987). Its value is only known in some areas of our coastline (Jiménez *et al*. 1997, 1999), but it has partly substituted the lack of fluvial supply in recent times, and has mitigated the erosive effects that might be expected.

At *decadal scale****,*** transport depends on the elevation and wave period and can be estimated through the analysis of tendencies, as shown in figure 11.8 (Jiménez *et al*. 1997).

At *medium-term scale (a few years),* the main factor is net longitudinal transport, which requires accurate knowledge of the mean wave height of each frequency interval. It has been seen empirically that on the Mediterranean coast the best results are obtained using a CERC-type formula with a proportionality coefficient that varies according to sedimentary characteristics and the coastal structures present (Sánchez-Arcilla *et al*. 2001).

Episodic events giving rise to the highest transport rates are associated with certain conditions of temperature, swell and meteorological tides and are the main “impulsive” reshapers of the Mediterranean coastline (Sánchez-Arcilla and Jiménez 1994). In order to study the swell climate of these episodes, intervals are used, because errors associated with the extremes of the probabilistic distribution intervene. The joint probabilistic distribution of significant wave height, the temperature and the maximum meteorological tide associated with “this” storm (for the Ebro delta coast) appear in figure 11.9, in which the asterisk indicates the conditions that caused the breakage of the "Barra del Trabucador" in 1990, and therefore, an "impulsive" morphological change.

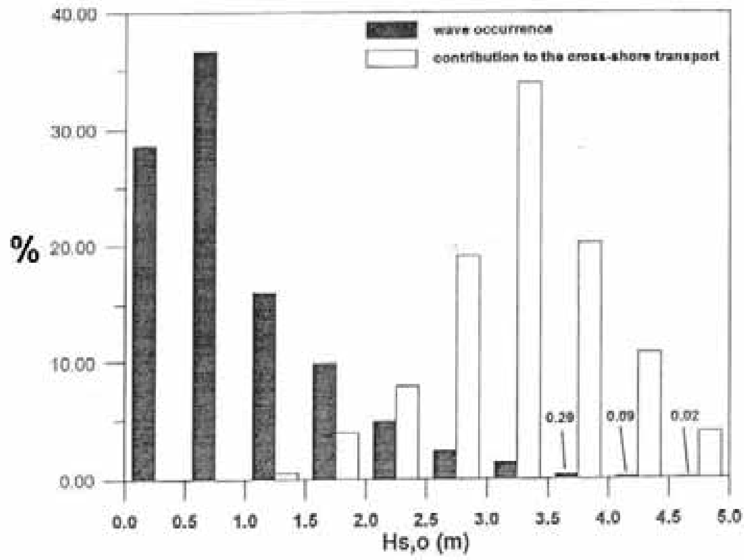

Fig. 11.8. *Contribution of wave height to transversal sediment transport (Jiménez et al.,1997)*

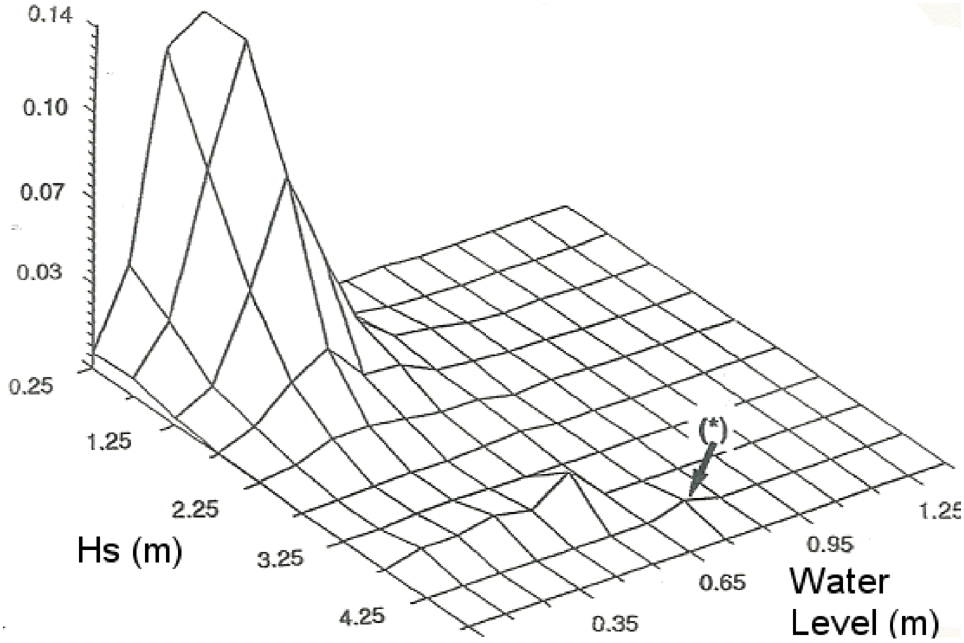

Fig. 11.9. *Joint probabilistic distribution of significant wave height (Hs) and mean sea level (Z). Note: the asterisk (*) indicates the conditions that broke the "Barra del Trabucador"*

A study to evaluate possible the effects of climate changes on coastal areas has been developed under a project carried out by the Universidad de Cantabria (Medina *et al*. 2004) for the Oficina Española de Cambio Climatico (Spanish Office of Climate Change) and the Dirección General de Costas (General Coastal Office of the Ministry of Environment). The study has been carried out by reanalysing datasets spanning 44 years (1958-2001) obtained by numerical simulation in which relevant metereological and oceanographical variables have been considered.

The analysis has allowed to study such variables and to perform a forecast of their future evolution. Considering 12 relative homogeneous areas, the mean, maximum and minimum values of the following variables have been calculated: direction of average flux of swell energy, wave height surpassed 12 hours per year and significant wave height. The results of the mean probability distribution are plotted in Figure 11.10. The extreme probability distribution has also been studied.

The study reveals that there is an evident increase of the swelling energy reaching to the Cantabrian Coast. The prevailing direction of the swelling tends to present an enhanced West component, with more intensity on the Western Coast. On the Galicia coast, the Cape Finisterre becomes the border between two zones with significant differences in the magnitude of the studied parameters. This gives rise to a smoother marine climate in the Rias Bajas; the swell energy tends to increase.

On the Mediterranean coast, although no relevant changes in the magnitude of swelling energy are detected, some marked peculiarities are obvious around Cape de la Nao due to its geographical position and, in addition, on the Costa Brava due to its proximity to the Gulf of Leon. On the Costa Brava, similar tendencies to the Northeastern Balear area are observed, displaying a reduction of the mean swell energy. Respect to the predominant swell direction, variations are found in the Ballearic Islands and on the Costa Brava, in which a tendency to a clockwise turn of swell has been obtained, resulting in a more eastern component of the predominant direction.

The Gulf of Cádiz displays a clear negative tendency for all the studied parameters, confirming the smoother maritime climate in such an area.

Finally, the results for the long-term variations indicate an increase of storms in the North and a tendency to an energetic reduction and a clockwise turn in the swell direction in the South. Changes in the wave height will affect the coastal flooding level, the sediment potential transport and to the extent of the beach active profile, among others. The variation of the angle of the mean flux energy may contribute to modifications in the beach shape and, in consequence, additional retreats together to the ones produced by sea level rise may occur.

11.3.3. River discharge

Liquid and solid discharge by rivers controls the biological productivity and quality of the water on the surrounding coast and the type and availabilty (volume) of unconsolidated sediment. Fluvial transport constitutes the main supply of sediments to the coast and is of particular relevance in the delta areas. There is a non-linear relationship between liquid discharge and sediment supply, but the present-day regulation of river basins has broken this (especially with regard to the sand fraction), and they will therefore be treated separately. It is very useful, however, to record liquid discharge in the form of velocities averaged on a daily basis, because these provide more information than those measured on a monthly or annual basis, which tend to camouflage specific processes. Indeed, there can be monthly measurements below the transport limit for a given sediment fraction, and, at the same time, the daily value can surpass this. Likewise, the impact of a possible climate change can go unnoticed within the averaged process but can be perceived with more “instantaneous” values. In this context, it should be pointed out that water management or use policies for river basins can accentuate, attenuate or eliminate the possible effects of climate change.

Liquid supply

The *long-term* discharge, in the context of this chapter, involving just a few decades, can only be estimated with the corresponding records, but taking into account actions aimed at regulation. For instance, for the river Ebro, they can only be taken into account after 1957, when the Ribaroja and Mequinenza reservoirs started functioning (figure 11.11)

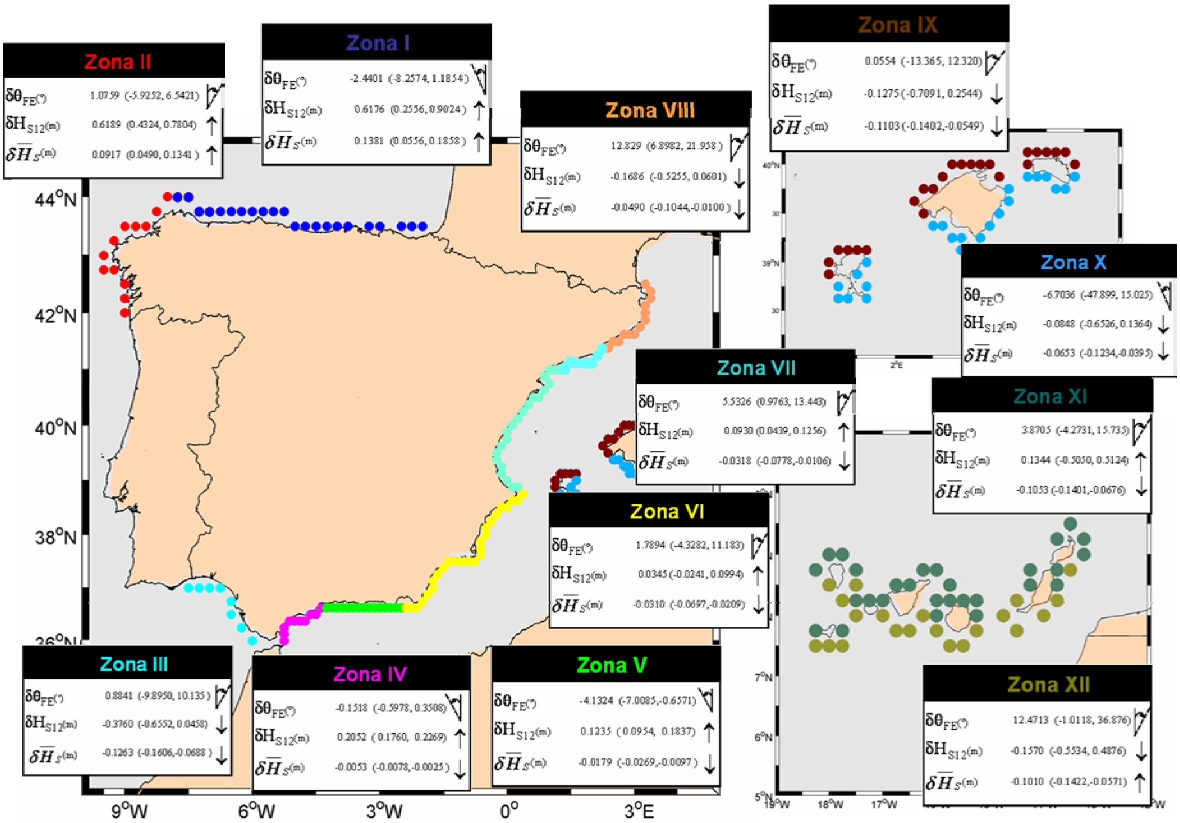

Fig. 11.10. Variations obtained for the values related to mean probability distribution of the swell (Medina et al. 2004)

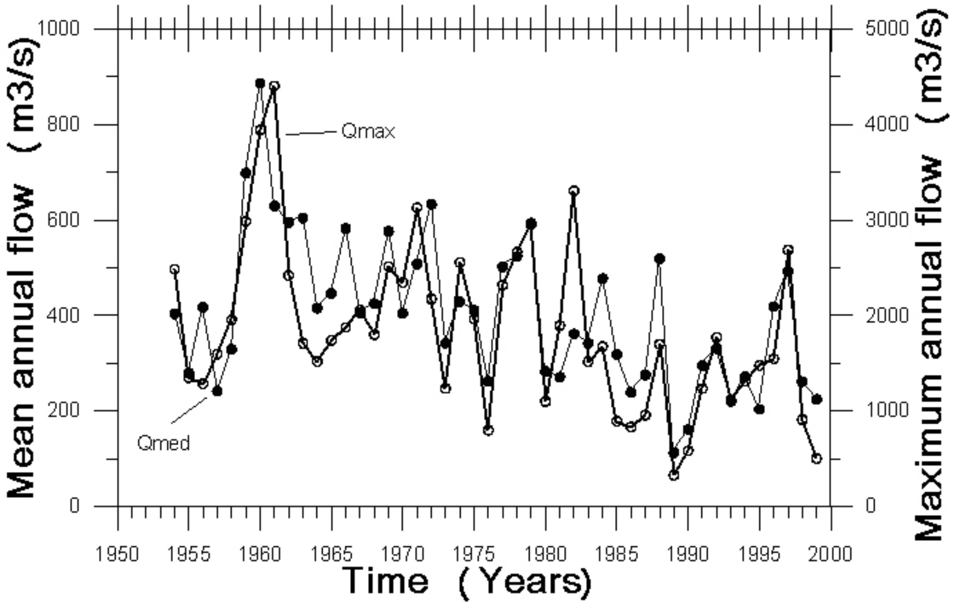

Fig. 11.11. Temporal evolution of the discharge of the river Ebro (Qmed = annual average and Qmax = annual maximum)

At *decadal scale* (figures 11.12 and 11.13), estimates of fluvial discharge are made with the use of trend analyses (Mitosek 1995) non-parametric tests (IPCC 1995) or in a simplified manner with the use of minimum squares regression analyses. Mean monthly and annual discharges are considered (Jiménez and Sánchez-Arcilla 1997). Trend changes in the context of decades should be analysed with care, because these can be of multiple origin: changes in climatology (and therefore in rainfall and surface runoff of the basin) changes in river regulation policy, changes in land management in the basin itself, etc. In strictly regulated rivers, as is the case of most Spanish ones, the impacts of possible climate change might very well go unnoticed.

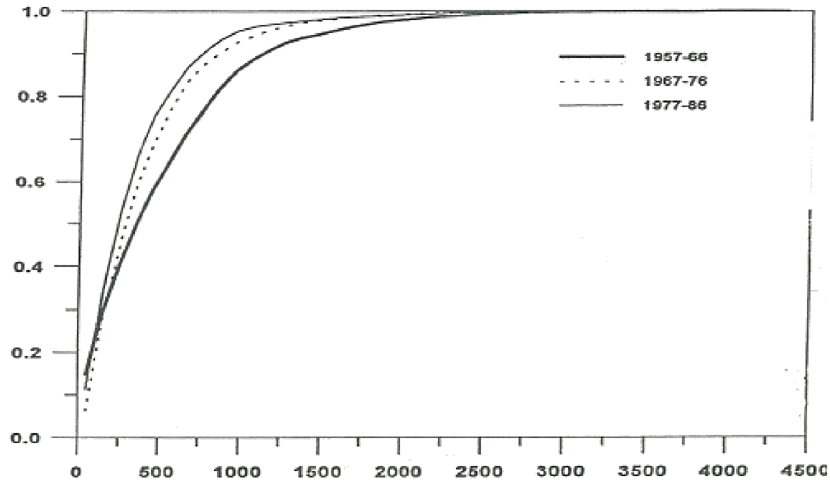

Fig. 11.12. *Probabilistic distribution of the discharges by the river Ebro, using flow- gauge records from 1957-1987*

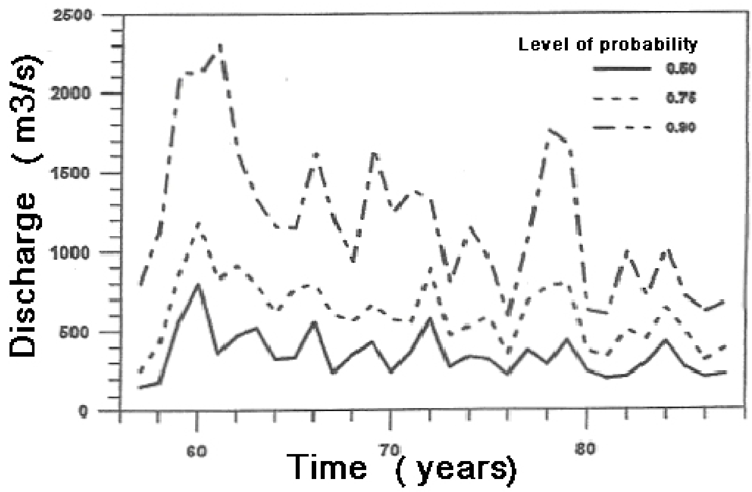

Fig. 11.13. *Variations in discharges by the river Ebro for a given probability*

In the *medium term* (a few years) shorter time series are required to analyse the underlying trends. We can generally expect a decreasing trend of the discharge in most (if not all) rivers of Spain. This is a serious disadvantage, because it hinders the choice of mean annual discharge, especially when this variable is taken as the “control” one. An example is given for the river Ebro in figure 11.14 (Jiménez and Sánchez-Arcilla 1997).

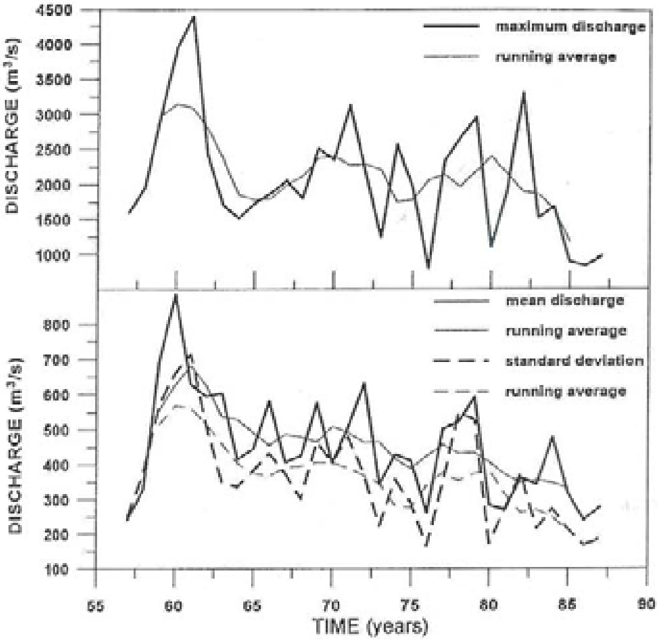

Fig. 11.14. *Temporal evolution of the liquid discharge of the river Ebro; (a) mean annual discharge; (b) annual maximums*

Espisodic events constitute the main contribution of the river to the volume and characteristics of the sediments on the coast, because they are the most efficient ones with regard to mobilising a solid discharge and, besides, it is precisely these that are most affected by local or regional climate change. It is difficult to quantify them, however, because even the episodic events in the present situation must be estimated using river discharge distribution extremes, which involves a high degree of uncertainty. Figure 11.15 presents an estimate for the river Ebro based on the annual maximums recorded since 1957 and using a Gumbel-type distribution. Any variation in discharge will lead to an increase or decrease in the solid discharge and a notable variation in the associated return periods.

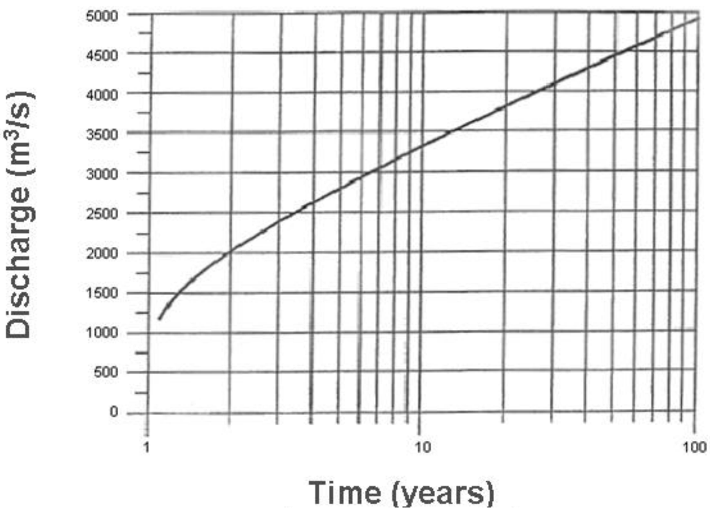

Fig. 11.15. *Regimen extremal for the discharges of the river Ebro*

The data on the liquid discharge of the rivers flowing to the South and East coasts are usually expressed in annual averages, taking their regulation system into account. With recent data from Water Basin Boards and other sources (Vanney 1970, Van Geen *et al*. 1997, MIMAM 2000), the mean discharges appear in table 11.2:

Table 11.2. *Liquid flows of rivers flowing to the coast*

River or basin	Discharge	Regulated (%)
Catalonia basins	1115	72
Ebro	12998	71
Júcar	1985	77
Segura	725	85
Sur	504	47
Barbate + Guadalete	842	44
Guadalquivir	7230	26
Tinto-Odiel	630	--
Guadiana	2525	75

Solid deposits

The solid discharge most directly affecting "external" coastal dynamics is the sand fraction or higher, transported as bed load by the river. The finer material is not stable on the coastline directly exposed to wave action, but it can contribute to the vertical dynamics of coastal lowlands and of the coasts of protected bays.

It is not easy to evaluate transport as bed load (Jiménez and Sánchez-Arcilla 1997) or to quantify it using direct measurements, because there is a very high degree of uncertainty (van Rijn 1993). Many formulae have been proposed, but the reliability and applicability of these are very limited and, in any case, they only indicate the theoretical transport capacity of the river in "ideal" conditions, without taking into account sediment availability or other limitations of real cases, an idea of which we attempt to establish using calibration parameters the value of which is unknown for our rivers. To this end, we can only consider the discharges in terms of order of magnitude. We can only obtain a time series of bed load discharges with the use of several formulae (Jiménez and Sánchez-Arcilla 1997).

In any case, and as we have already mentioned, it must be remembered that sediment supply by rivers in the recent past has been more conditioned by human activity in the basins or in the watercourses themselves than by climatic factors. We can expect the same thing to occur in the future.

By way of an illustration, the mean solid supply of the river Ebro was estimated for the sand fraction at 30,000 m3/year. The mean supply of the river Guadiana for the different sediment fractions and in the last four decades was estimated at 1 Hm3/year.

11.3.4. Precipitation

The possible effects in the coastal area of changes in the rainfall regime are more related to rainfall in the river basins than with rainfall on the coast itself. Projections by climate models indicate a decrease in total annual rainfall and a small variation in the frequency and/or intensity of torrential rainfall, which is more significant from the point of view of possible effects, as the coincidence of intense rainfall and storms establishes the ideal conditions for cliff slides. These processes, however, are restricted to relatively small sectors of the cliffs, of which only some present human structures in risk areas. Furthermore, the increase in the frequency and/or intensity of storms in the river basins can give rise to an increased risk of flooding in the lower courses and areas close to the river mouths, particularly the coastal lowlands in the vicinity of the estuaries. These effects will naturally be exacerbated with a local over-elevation of sea level due to meteorological causes, low pressure or spring tides, or in a permanent and general manner, due to a rise in mean sea level (MSL). .

Obviously, changes in the rainfall regime (and possible related flood events) could affect river supply of sediments and other substances to the coastal area. With regard to sediments, the available data suggest that the alterations resulting from human activity are much greater than those caused by climate changes. In some estuaries in the North of the Peninsula, sedimentation rates have increased one order of magnitude during the 20th century (Remondo *et al*. 2003). Climate changes detected in this period are very slight and do not reasonably account for this increase; increased human activity seems to be the most reasonable explanation. We could expect this to be valid, too, for deposits of pollutant substances (livestock farming and agriculture, industrial or urban), which are much more conditioned by the type and intensity of present and future economic activities and of the corresponding preventive or corrective measures, than by changes in rainfall patterns.

11.4. MOST VULNERABLE AREAS

11.4.1. Vulnerability and risk

A detailed analysis of the risks for the whole coast is not among the objectives of this study, but we can make a qualitative evaluation of these and present quantitative estimates for certain specific cases.

What is understood as vulnerable areas are those that can suffer some kind of damage as a direct or indirect consequence of climate change, due to being subjected to some type of risk, risk being understood as total predictable material losses. In the context of this analysis, it would be of interest to estimate the risk in vulnerable areas, which obviously depend upon the processes acting in each area, and upon the intensity of these.

Losses (risk in the context of this analysis) are estimated according to the *exposure* (existence of damagable elements in areas that could be affected by processes representing a potential danger), the *vulnerability* (sensitivity of the existing elements to these processes, or fraction of their total value that would he damaged) and the *hazard* (probability of occurrence and magnitude of a dangerous process in a given period of time, or recurrence period thereof, in a given land unit).

11.4.2. Probability of failure or risk

The risk or probability of failure of the system should be quantified taking into account the temporal and spatial scales considered, and the uncertainties involved in the calculation. Likewise, damage assessment should consider these scales of time and space and use a procedure that incorporates both the positive and negative response of the system. The negative response, or susceptibility, indicates the degradation of the system, or the incapacity of this to deal with modelling agents in their current state. The positive response, or “resilience”, implies an improvement in the system or its capacity to deal with the impulsive agents.

Here we should consider, on one hand, the likelihood of short-lived violent episodes (storms and tsunamis) in the future. And, on the other, the probability that, within the temporal horizon considered in this analysis (decades, centuries), there will be a rise in sea level of a given magnitude. This probability can be estimated with the use of two procedures: a) empirical, based on the analysis of change trends in the last century and the extrapolation of these according to different scenarios; b) deterministic, based on climate models.

As a whole, it could be said that we are now faced with a “high risk and high uncertainty” situation. The potential damage caused by failures in the coastal systems resulting from climate change is very great, but there is also considerable doubt with regard to the magnitude of these changes. The main uncertainty refers to possible changes in the frequency and intensity of storms and the magnitude of the rise in MSL.

11.4.3. Damage

As we mentioned previously, the vulnerability of coastal areas to climate change essentially involves two types of units: beaches and coastal lowlands in the vicinity of estuaries and deltas.

The vulnerability of these areas basically corresponds to three types of situations or characteristics: a) presence of structures or property with market value that represent “capital subjected to damage”; b) existence of natural elements of no market value, but which are the basis of economic activities and which could be negatively affected; c) existence of valuable natural units, not necessarily directly associated with economic activities, but which could suffer deterioration.

The first area fundamentally corresponds to areas at risk of potential flooding, in a permanent or intermittent way, in which the value of land and crops, buildings or infrastructures existing therein could be affected. These areas mainly exist in the vicinity of deltas and estuaries, and in many cases, correspond to old wetlands or desiccated intertidal areas. There are also certain areas, not very numerous, situated above all at the upper part of beaches, with buildings or structures that could be affected by a rise in sea level and/or more intense storms or tsunami-type events.

The second group essentially comprises confined beaches, which could suffer a considerable area reduction or even totally disappear.

The third group includes wetlands and supra- or intertidal areas, which could disappear as a result of a rise in sea level, although this disappearance would probably be partially compensated by the appearance of new wetlands in coastal lowlands such as the ones previously described. The degree of vulnerability of the dune fields associated with beaches is lower, although in some cases, their area might be reduced or they might disappear as a consequence of a rise in mean sea level or more intense storms.

Analysis of likely damage should take two aspects into account: On one hand, possible losses of “capital” (damage to infrastructures or buildings, loss of land, etc.). On the other hand, we should also consider the losses caused by the different disturbances that can affect various types of economic activities. The former is easier to deal with, as it refers to material elements existing in the territory, whereas the latter involves much greater uncertainty, especially if we take into account the great difficulty involved in making predictions with regard to the economic activities that will take place several decades from now.

11.4.4. Delta areas

The delta areas, currently out of balance due to the shortage of river sediment supply that generated them in the first place, are a good example of threatened areas presenting a high risk of disappearance. The concentration of human values (e.g. Llobregat delta) and natural ones (e.g. Ebro delta) existing on them account for their degree of vulnerability.

In order to apply these concepts to a coastal process, the appropriate temporal scales must be introduced. It is also convenient to use a vulnerability index summarising this information, which is often fuzzy and inaccurate, through a limited set of parameters. Sánchez-Arcilla *et al*. (1998) have proposed a partial vulnerability index:

$$Vi = Qi \cdot Si \cdot Lc + Ri \cdot Lc$$

Where *Si* is the susceptibility index, *Ri* is the resilience index, *Lc* is a local control factor that acts as 1 or 0 (eventually an intermediate value) and *Qi* is an index that reflects the area of the process analysed.

An illustration of the binary evaluation of susceptibility or resilience indices for certainsection coastal sectors appears in table 11.3. An application of this methodology to long-term susceptibility or resilience indices for a delta area (the Ebro delta) appears in table 11.4.

Table 11.3. *Susceptibility (SI),and resilience (RI) indices and response by the associated system used, to be used in the vulnerability analysis.*

Analysis type	Measure	Response	SI	RI
Absolute	Change of "resource"/	Decrease	-1	0
	Stock	Maintenance/increase	0	1
Relative	System under scenario/	Worsening	-1	0
	Reference	Improv./no change	0	1

Table 11.4. *Susceptibility (SI) and resilience (RI) indices in the long term for agents affecting geomorphological vulnerability and processes associated with this scale. "?" means that an a priori assessment cannot be completed without knowledge of the final consequences.*

Agent	S.I.	R.I.	Response
River discharge	-1	0	Decreased transport capacity
	0	1	Increased transport capacity
RSLR	-1	0	Vertical accretion < RSLR
	0	1	Vertical accretion = RSLR
RSLR	-1	0	Coastal erosion
	0	1	Stability/coastal accretion
Barrier processes	-1	0	Limited rollover
	0	1	Increased rollover
	-1	0	Transport capacity increases
Wave climate	0	1	Transport capacity decreases
	?	?	Transport direction changes

The assessment in the case of episodic events, the most determinant ones for remodelling the physical substrate in any section of coast, appears in table 11.5 for the Ebro delta area. A schematic representation of these indices, with their corresponding area of spatial definition for this same delta area, appears in figure 11.16. An assessment of the corresponding vulnerability at medium-term scale appears in figure 11.17. As can be seen, the vulnerability map changes appreciably according to the time scale chosen.

Table 11.5. *Susceptibility (SI) and resilience (RI) indices at episodic scale for agents affecting geomorphological vulnerability and processes associated with this scale*

Agent	S.I.	R.I.	Response
Fluvial switching	-1	0	Abandoned lobe
	0	1	New lobe
Fluvial switching	-1	0	Deposit of "protected" sediment
	0	1	"Exposed" deposit
Floods	-1	0	*wash-out* sediment
	0	1	Deposit sediment
Wave storms	-1	0	Erosion / breakage
	0	1	deposit hinterland sediment

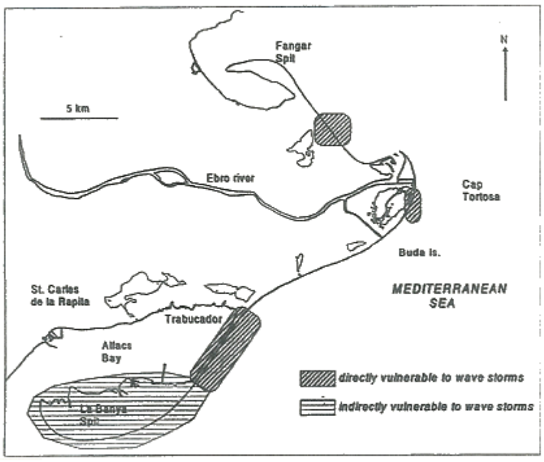

Fig. 11.16. *Qualitative vulnerability index at "episodic" scale for the Ebro delta*

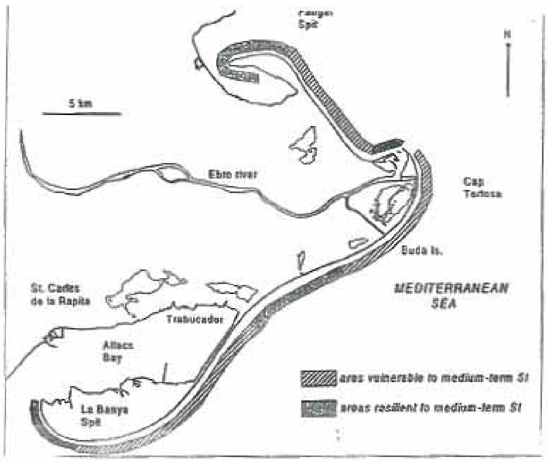

Fig. 11.17. *Vulnerability caused by changes brought about by sediment transport along the coast in the medium-term in the coastal area of the Ebro delta*

Evaluation of the joint vulnerability of the system, taking its different components into consideration, requires a wider analysis framework. It is therefore necessary to schematise the coastal section and to specify the impulsive agents, and the corresponding associated processes, as both of these affect the uses and resources in the coastal sector. Figure 11.18 shows a conceptual diagram applied to the Ebro delta coastal area. The key point of this diagram is the identification and subsequent quantification of the flows linking some elements with others. These flows vary in magnitude and even in definition with a change in time scale. For instance, irrigation practices and the construction of dams and reservoirs do not affect short-term coastal erosion, but they play a determinant role in coastal dynamics in the medium and long term. This is due to the control both elements have over the solid supply that the river transports to the coast.

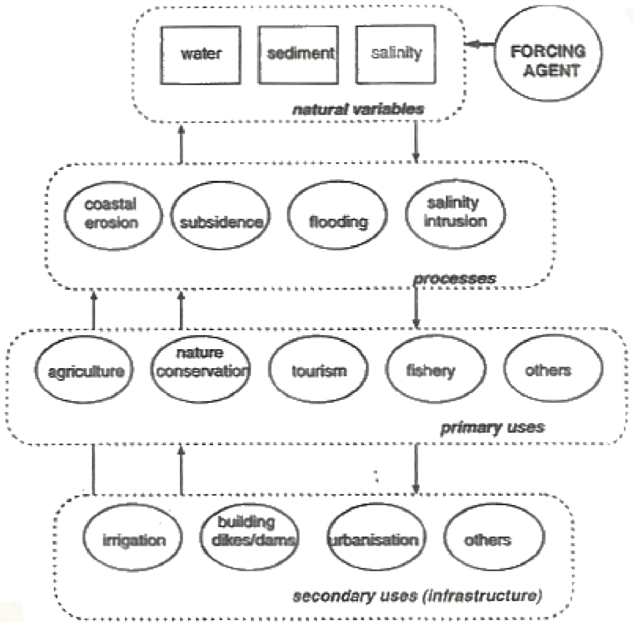

Fig. 11.18. *Diagram of the delta system according to main processes and uses (adapted from Otter et al. 1996)*

11.4.5. Beaches and coastal lowlands

The values and functions of beaches differ with regard to both their nature and location. The biotic communities they contain are not especially rich or varied, but they are very specific to these environments. Due to their diversity, scarcity and endemic condition, the communities of the dune fields associated with some beaches should be highlighted. Furthermore, their importance as a base for the development of activities related to the tourism and recreation sector is well known. We must also consider the coastal geotopes or physical support on which these ecosystems become established. These geotopes contain sediments and morphologies that can easily be dated, and represent sources of information needed to decipher the climatic history of the last few centuries or millenia, and thus help to estimate future change trends

A rise in sea level will bring abaout a displacement of beaches or a retreat caused by erosion, with a reduction of their total useful area. This retreat will depend on the specific characteristics of each beach and it is not possible to present a detailed analysis of each case. By applying Bruun's rule (1962, 1986, 1988), which establishes an advance by erosion of 1 m for every centimetre of rise in sea level, and considering the confined or unconfined condition of beaches, as well as their width, it can be estimated that a rise of 0.5 m could cause the disappearance of 22 km of the length of the beaches in the Basque Country and Cantabria, which is the equivalent of approximately 30% of the total (Table 11.6). As is logical, this disappearance will fundamentally affect narrow confined beaches with gentle slopes. Wider beaches (>50 or 100 m) will be reduced in area, without disappearing. This estimation is based on a hypotetical absence of additional supply of sediments by natural or human-induced causes. Obviously, an increase in the sediment response will reduce the values of table 11.6.

On unconfined beaches, especially spit bars and sand ridges associated with dune fields, the areas loss can be expected to be much less or even nil, although the adjacent dune fields will probably be reduced.

However, it is worth remarking that the assessment of climate change effects based exclusively on the sea level rise is an obvious simplification. A more precise analyse should include the effects derived from the variations in swell height, period and direction.

Table 11.6. *Summary of the characteristics of the beaches in Cantabria and the Basque Country, along with a semi-quantitative estimate of the the likely effects of two scenarios of a rise in sea level on the beaches of Guipúzcoa, Vizcaya and Cantabria, by applying Bruun´s rule (modified from Rivas and Cendrero 1995).*
(1) Spit bars or beach ridges. Some of these are confined along some of their length by cliffs (e.g. Oyambre) or by artificial structures (e.g. Zarauz) and a part of these beaches will therefore also disappear with a rise in sea level.
(2) The reduction will be even greater, as the average width of the beaches has been taken into account, but the width of many of these, along much of their length, is much less than this average figure.

	Confined beaches			Unconfined beaches (1)
	Present	Rise 50 cm		
Number of beaches	95	33	35 %	17
Guipúzcoa	17	12	70,6%	2
Vizcaya	22	10	45,4%	3
Cantabria	56	11	19,6%	12
Lenght (km) (2)	45	23,6	51,9%	25,4
Guipúzcoa	9,42	6,6	70%	2,85
Vizcaya	9,2	5	53,4%	1,5
Cantabria	26,37	12,15	46,1%	21,1

The strip of sand constituting the natural border between land and sea in these coastal lowlands in the Mediterranean environment has been gradually disappearing over the last few decades, mainly due to the alteration of the sediment balance in the coastal area, the net result of which is the alarming decline in sediment input, and, as a consequence, the retreat of the coastline and the loss of beaches.

The main inputs of material involve supply by rivers, transport of material along the coast by longshore drift, sediment exchange between the beach (*backshore*) and the dune systems due to the action of the wind, and the seasonal exchange of sediment between the sub-aerial "beach" (*foreshore*) and the submerged "beach" (*shoreface*). All of these have been modified by human intervention.

The progressive decrease in fluvial sediment load due to the construction of dams, river regulation and the fight against erosion in drainage basins, together with the construction of coastal and port structures have led to a drastic decrease in the natural evolutionary capacity of the coast, as they limit the capacity for movement of the different sediment masses from one coastal segment to another. This has unleashed erosion processes and the retreat of the coastline. Furthermore, the occupation of the upper part of the beach prevents the recovery of the profile following the highly erosive storms that occur mainly in wintertime.

The occupation of *backshore* and dune belts, subsequent to massive development along much of the Mediterranean coast, has not only used up a large part of the beaches' natural sand reserves, but has also altered wind dynamics, creating real "corridors" between the higher buildings, through which the wind is channelled, thus increasing aeolian erosion in certain parts of the beach.

The construction of port and coastal structures, apart from contributing to the rigidity of the shoreline, has limited coastal dynamics and the capacity of the system for natural recovery following storms and floods. Such structures act as sediment traps upstream from the drift, leading to erosion downstream, as an attempt by the coastal system to recover sediment balance.

This is the case on the Atlantic coast of the Gulf of Cadiz, where the many existing structures (in an area of high natural variability, resulting from the presence of large inlets, interfere with longshore drift and increase the erosion of the soft cliffs in favour of some beaches, such as those to the west of the Guadiana and Odiel-Tinto estuaries.

The degeneration processes began with the development of tourism and of the economy in the 60s (for example, the Ribaroja-Mequineza complex, which affected the whole Ebro delta, or the housing development in La Manga del Mar Menor). In short, the intervention policy along the coast, together with the obstruction of natural dynamics (fight against river and sea flooding and prevention of the associated silting processes) has accelerated erosion processes on a strandline subjected to great pressure by urban, recreation, port and infrastructure uses. A good example of this is the Maresme coast in Barcelona, made up of a quasi-continuum of housing development and "rigidised" by a railway line and a road running close to the shoreline, and often separated from this only by a longitudinal rockfill.

Furthermore, the high level of occupation of the coastal fringe, particularly of the partially consolidated sand barriers in the coastal lowlands (for example, from Guardamar de Segura to Torrevieja in Alicante and La Manga del Mar Menor) causes increased subsidence due to overload.

On the coastal lowlands of Malaga and, above all, Almeria, the problems lie in the use of the natural coastal alluvial plains for greenhouse crops, with the consequent re-mobilisation of the natural soils and the overexploitation of the aquifers, which cause salinisation.

Another problem involves the loss of environmental quality of the waters, which damages the fields of *Posidonia sp.* and other ecosystems, the loss of which might eventually affect climatic balance. One of the points most affected is the area facing La Manga del Mar Menor. This area should be carefully monitored, especially with regard to the construction of new coastal and port infrastructures or water desalinisation plants. The possible impact of a rise in MSL in the near future should be carefully estimated here.

11.4.6. Estuary areas

These units present a high diversity of socioeconomic and natural values, and therefore greater vulnerability. Estuaries contain some of the main ports along the N, NW and SW coasts and also many of the main population settlements, and much of the economic activity takes place in those areas. There is a considerable potential for tourism and recreational activities, thanks to the landscape value of many of the estuaries and bays, the associated beaches (both inside and at the river mouths), possibilities for sailing, etc. The estuaries are associated with large intertidal areas and wetlands with high biodiversity and biological productivity, and these are very important for the fisheries sector, both directly (traditional fishing, shellfishing, aquaculture) and indirectly, as they are the breeding and/or feeding grounds of many species. However, throughout much of the XIX and XX centuries, the desiccation and infill of many wetlands and marshlands was carried out in order to use them for urban areas, industrial estates, infrastructures, agriculture, etc. This generated large areas that sustain considerable public and private real estate capital (high-value land, buildings, infrastructures, services, etc.). This pressure caused by occupation probably constitutes the main threat affecting these areas at present.

The predicted damages in the vicinity of estuaries or much smaller-area lowlands, associated with snad bars not linked to the mouths of significant water courses, are due, above all, to the rise in mean sea level and to the risk of flooding of old wetlands and intertidal, desiccated wetlands, which were not filled, or which were only filled with a thin layer (Cendrero and Díaz de Terán 1977; Cendrero *et al*. 1981). Many of these areas are occupied by buildings (residential, industrial, services, infrastructures); some of them are less than 1 m above current spring high tides, and a rise in sea level would therefore seriously affect them. One way of estimating the risk for these areas is to consider certain scenarios of sea-level rise, delimiting the areas that would be affected by these rises and making an inventory of the property existing therein ("capital at risk").

An estimate was made of the potential damage a rise in sea level would cause along the coasts of the Basque Country and Cantabria (Rivas and Cendrero 1991, 1995). The procedure used is illustrated, for a small estuary, in Figure 11.19. A representation of the areas that could be affected (for a scenario of a 1.5 m rise, greater than what is considered to be reasonable in this study) is shown in figure 11.20. It is estimated that in the Basque Country and Cantabria, rises of 0.5 and 1 m would affect, respectively, around 25 and 79 km^2. The estimated value of the "real estate" capital at risk for all three provinces analysed would be, respectively, 820 and 8370 $x10^6$ US$ (1991 figures not updated to 2004 prices; Cendrero *et al*. 1981; Rivas and Cendrero 1991,1995). These figures consider the total loss of the land, buildings and infrastructures existing therein. The real loss of capital, considering that most of the buildings have a limited useful life, generally shorter than the end-of-century horizon contemplated, would be less.

With regard to the marshlands and intertidal areas that maintain their ecological values, two cases should be highlighted: if there are adjacent coastal lowlands, these areas will be displaced inland as sea level rises; this could particularly affect areas that were previously desiccated but that had not been filled. To the contrary, when wetlands cannot be displaced inland, they can be expected to diminish or disappear. It is therefore very important to identify the possible prevention or mitigation alternatives.

A rise in sea level of the magnitude previously mentioned would most likely lead to the recovery of a large area of wetlands and intertidal areas, which would represent a positive impact. Some of the areas below 0.5 m are simply isolated and desiccated or used for agriculture or forestry, or even are not used, and they could therefore recover their original functionality as wetlands or intertidal areas in a period of a few years, either through spontaneous recovery processes set in motion by abandonment, or as a result of deliberate restoration actions (for example, breakage of the existing barriers), even without any change in sea level. In the case of a rise in sea level, practically all of these areas would become wetlands. If there were to be a rise of 1 m, the areas that could be recovered as wetlands would probably exceed 30 km^2. Although there are no detailed analyses that could enable us to quantify this effect, it seems unlikely that the net result will involve a big change in the total wetland area, and these would essentially be displaced.

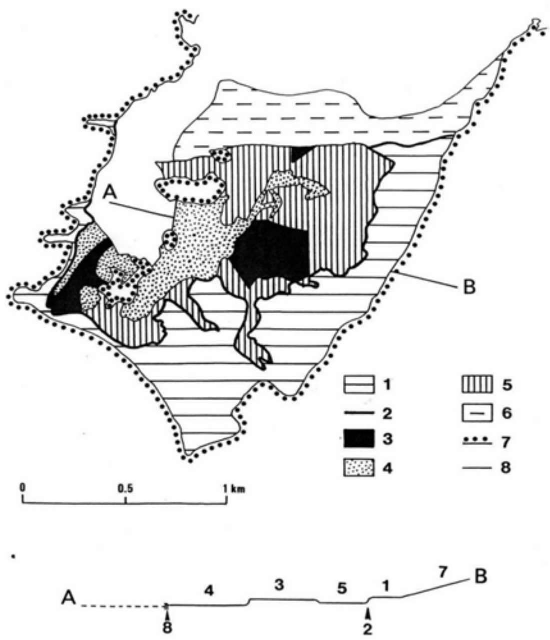

Fig. 11.19. *Procedure for identificationand mapping of areas at risk in the vicinity of a small estuary (Rivas and Cendrero 1991)*

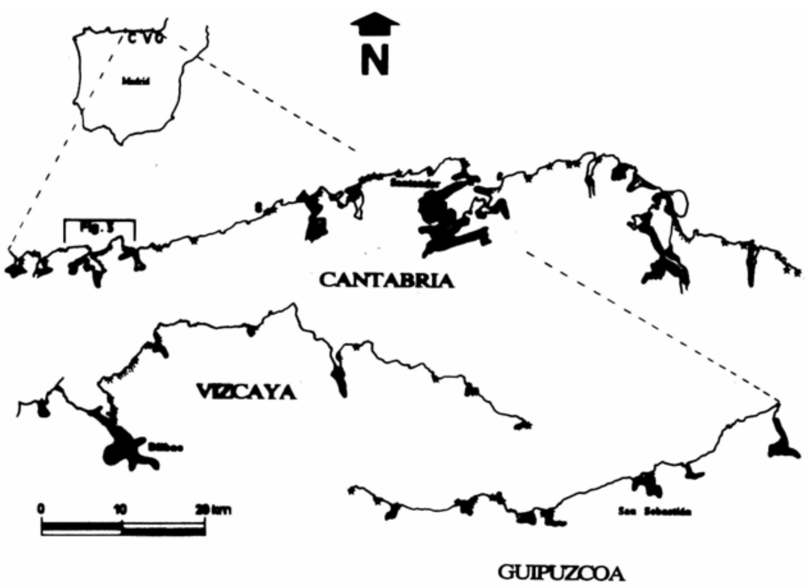

Fig. 11.20. *Areas that could be affected by a scenario of a 1.5 m rise, greater than what is considered to be reasonable in this analysis (Rivas and Cendrero 1990)*

Special mention should be made of the beaches associated with estuaries. As has been explained before, some of these beaches may disappear, but others, such as sand spits at river mouths, will be more frequently subjected to *overwash* events (in storms with very high waves) and lateral displacement of harbour mouths, and finally displacement inland. This apparently contradicts the results by Rodríguez Ramírez *et al*. (2000) who observed that, in the last few years, the growth of beach crests, that is, the progradation of the litoral spit bars occurs during periods of higher sea level. The explanation is that there are small rises of little duration after which the usual situation of “low sea level” is re-established. However, in the case of the supposed rises in MSL in the scenarios of this study, the magnitude of the rise is greater and, besides, the level will remain high and the over-elevations will occur when these high values are reached.

Furthermore, they are also vulnerable to changes in the rainfall regime, fluvial discharge and floods, especially if these increase and coincide with a rise in MSL. This would cause an increase in the frequency and/or magnitude of the floods. We must also take into account changes in the supply of sediments or other substances (nutrients, pollutants) that can derive from changes in river regimes. Lastly, an increase in mean sea level will give rise to greater penetration of the saline wedge into the water courses and to an advance of the freshwater/saltwater interphase of the aquifers.

11.4.7. Soft cliffs

The potential threat in the areas with cliffs depends very little on climate change, and mainly involves the growing pressure from housing development along their length. In the few sectors with “soft cliffs” presenting significant retreat rates and which contain buildings or structures, changes in the oceanic climate and sea level can lead to an increase in these rates, with the consequent risk for the adjacent buildings.

In the case of cliffs, even of the “soft” typology, a rise in sea level of around 50 cm or 1 m would not have any significant effects. In the case of the coasts of Cantabria and the Basque Country, a total of 9 km of cliffs with a marked erosion rate has been identified, and in only two places a problem might arise, one in Cantabria and another in Vizcaya. It has been indicated that in the first of these (Oyambre beach), an acceleration of the retreat rates has been detected since 1946, up to values of several metres per year in the 90s (Rivas 1991; Rivas and Cendrero 1995).

On the Atlantic coast of the Gulf of Cadiz, soft cliffs represent over 50% of the coastline, and are subjected to intense erosion which, in the Mazagón area, presents a rate of between 1.25 and 2.2 m/year (Rodríguez-Ramírez 1998). This is mainly due to the interference of the Dique de Juan Carlos I (Juan Carlos I Pier) which, with a length of 14 km, has interrupted logshore drift and accelerated erosion downstream and favoured the accumulation of a 4 km-long beach attached to the pier upstream, in the old “Banco del Manto”.

11.5. MAIN ADAPTATIONAL OPTIONS

Classical coast management strategies, also applicable to a future climate change at regional scale causing a relatively rapid rise in MSL or a change in the characteristics of storms, include retreat, adaptation and defence.

The *retreat strategy* requires, in the first place, the necessary available space to re-locate activities and resources in the coastal sectors cocerned. If space is available, this strategy is the one that is most in concordance with the big uncertainties in relation to the prediction of climate change at regional scale and, furthermore, it does not reduce degrees of freedom for future decisions in the area.

The *adaptation strategy* requires a different approach for erosion and flooding as well as social and economic flexibility, given the degree of uncertainty of the predictions. In the first case, the strategy for combating erosion, from the adaptation point of view, requires the emplacement of certain soft structures and flexible use of the land-sea interphase. At present, the most commonly used strategy involves the use of vegetation for support and dissipation, aimed at reducing erosion risks. In the second case, the risks and costs associated with flooding can be predicted, although with a certain degree of uncertainty, and, in any case, all the users and managers of the coastal area must be familiarised with them. It should not be forgotten that flooding defences would require continuous maintenance and eventual re-growth, if the coastal sector were to suffer subsidence or if there were to be a eustatic rise. This practice is applied in countries like Holland, which wage a secular war against this type of problems.

The *defence strategy* is the one that society usually prefers, due to its “apparently” monolithic nature in relation to erosion or flooding. This involves initially high costs, but we should also remember that it requires maintenance costs, as can be seen, for example, in the history of the defence and protection structures on the Maresme coast. This defence strategy can therefore only be considered for certain coastal sectors, always keeping the time factor in mind and, what is very important, the degree of uncertainty of the structural resistance of the solution adopted, like, for instance, its functional design.

The best solution for any temporal scale chosen consists of combining the three elements, all of this within a framework of an integrated plan for the coastal area.

11.5.1. Beaches

In *unconfined beaches*, the most recommendable strategy, in general, is the one involving retreat, as this is the natural behaviour to be expected in the case of beaches and associated dune fields. In certain cases, this might involve the invasion of areas containing elements of interest.
The strategy of non-structural intervention involves the prompt establishment of land planning laws aimed at preventing new structures or activities in vulnerable areas. Initially, this should be a task at municipal level, and should be based on town planning revision, with the help of specialists and technical advice by the appropriate organisations, in order to delimit the vulnerable zones. It would therefore be necessary to set a time limit for municipalities to carry out this task.

This strategy should provide for the progressive abandonment of the buildings, infrastructures, croplands, etc., located in the vulnerable areas, and this presents two limitations: accurately determining the areas that will be affected, and, in particular, when the damage will occur. We should therefore work within the range of possibilities corresponding to the “optimistic”, “pessimistic” and “most likely” predictions. Given that abandonment represents a “de facto” transfer of private property to the public domain, indemnity, compensation or expropriation plans should be drawn up, and the impact of the limitation of the owners’ rights to use should be compensated for.

When the migration of the beach and/or the dune inland represents a loss which is considered to be unacceptable, the strategy of artificial nourishment or structural intervention should be implemented. In both cases, a line of maximum retreat should be indicated, in order to allow for better planning of the coastal area. Thus, apart from delimiting the areas that could be affected by the migration (considering the different scenarios), vulnerable property or elements existing therein should be inventoried and valued, in order to determine what requires protection and compare their value with the cost of necessary protection measurements. This analysis should obviously be made for each case in a detailed manner, within the context of the aforementioned revised town planning.

The situation is very different for *confined beaches* because if there is no structural intervention, the useful area of some of them will be reduced and will disappear in other cases. On the beaches that have been stabilised with the use of groins, piers and other coastal structures, the impact of local climate change is difficult to predict. The behaviour of the coastal structures will vary appreciably (Sánchez-Arcilla *et al*. 2004) with any change in mean sea level or in wave climate. The functional design of coastal protection should therefore be reassessed, and the durability of artificial sediment nourishment should also be included.

The urgent need to promptly establish a strategy in this sense is clearly illustrated by the data presented in section 11.4.5.

11.5.2. Soft cliffs

The options in this case are more simple, given the fact that in very few cases are there structures or buildings that could be affected by cliff erosion, and, in any case, this would be clearly of lesser magnitude than the migration of beaches.

One exception is the cliffs of the Costa Brava which, due to their high density of fractures and high level of housing occupation, constitute a coastal problem of increasing importance.

The retreat strategy, aimed at allowing nature to follow its course, would have implications similar to those described for beaches susceptible to migration. It would also be necessary here to delimit the areas that might be affected, to inventory and value existing property, establish use limitations in certain areas and provide for the abandonment of buildings, etc. (and the consequent compensation).

If the abandonment of certain structures subjected to potential risk is considered to be unacceptable, the installation of protection elements will have to be provided for (for example, block barriers at the foot of the cliffs). The valuation of the property to be protected and the comparison between this and the protection costs will obviously be used as a base to decide which strategy is to be implemented in each case.

Given the existing uncertainties with regard to the materialisation of the threat, follow-up and monitoring systems should be put into practice in order to determine to what extent the risk is real and requires intervention. These systems can range from the simple placement of set of reference points, perpendicular and parallel to the cliff edge, and *in situ* visual surveillance, to continuous register systems or detailed photogrammetry at regular intervals.

11.5.3. Coastal lowlands

The situation of delta coastal lowlands is very much threatened by the lack of sediment supply. The remodelling capacity of climatic factors is maintained, while the volume of the sedimentary body diminishes steadily. The adaptation strategy based on maintaining a dynamic border between land and sea allows the duration of the delta sedimentary body to be maximised. Mitigation is more complex to implement in practice. Local mitigation with the use of sand, partial fixation with the use of vegetation or total, rigid fixation using structures is costly and difficult to sustain. A general mitigation system for the delta body based on sediment supply, for instance, through natural peak discharges or controlled reservoir discharges, is therefore considered to be more advisable.

From the point of view of mitigation strategies, the situation of wetlands and intertidal areas is comparable to that of beaches and dunes. Some of these wetlands, both the ones associated to estuaries and the few that exist outside them, can migrate inland, occupying the adjacent coastal lowlands. The retreat strategy will surely be the most suitable one in most cases, as it will generally allow the total area of these to be maintained. If this option were to be taken, the abandonment of the land and structures that could be affected would need to be provided for. If this option were to be considered unacceptable, due to the existence of buildings, structures, etc., that need to be maintained, protection walls or dykes would need to be built, along with pumping systems to avoid a rise in the phreatic level ("Dutch solution"). In certain areas, additional filling and elevation of certain structures could be considered (for instance, the airport runways of Fuenterrabía and Santander).

In other cases, the migration of wetlands inland becomes impossible, due to the presence of different types of barriers. If there is no alternative the final result will be a reduction of the area of wetlands, which will become totally or partially submerged. In other cases, it will be possible to eliminate the barriers, (for example, in areas that have simply been closed off and drained), thus facilitating the migration and/or regeneration of areas previously occupied by wetlands. It has been estimated that on the coast of the provinces of Guipúzcoa, Vizcaya and Cantabria there could be around 30 km^2 of areas with these characteristics, that is, potentially recoverable.

11.5.4. Ports

The local climatic impact on port infrastructures essentially refers to the levels of infrastructures and their capacity for resistance. The first point is illustrated by the level of dyke tops (which condition the overflow volumes) or by the area of dykes exposed to more rigorous conditions. The point of resistance capacity is therefore based upon a change in MSL and on the intensity, duration and recurrence of storm surges. All of this requires re-evaluation of the reliability of coastal structures.

11.6. REPERCUSSIONS FOR OTHER SECTORS OR AREAS

11.6.1. Interaction with the hinterland of the coastal area, including the drainage basin of rivers

A rise in mean sea level would cause a rise in the base level of rivers, which would lead to increased sedimentation in the lower courses of these, especially in estuaries, which will have repercussions for the maintenance of ports. It is not possible to evaluate the relative importance of this factor in comparison with the variations in sediment supply caused by changes in land uses in the river basins. It will also cause greater penetration of the salt wedge into the estuaries, displacing the sedimentation zone inland, through flocculation.

An increase in MSL will probably also determine greater frequency and intensity of flooding in the lower courses of rivers, and this effect will be accentuated if the intensity and frequency of torrential events were to increase.

11.6.2. Interaction with fisheries

A reduction of wetlands and intertidal areas would affect biological productivity, as these are high-production areas and are fundamental for the reproduction and/or feeding of different species of interest. It is therefore important to facilitate as much as possible the migration of these areas landwards, in order to maintain (or even increase) their total area.

11.6.3. Interaction with tourism

The tourism sector is the one that will probably be the most affected, due to the reduction or disappearance of many beaches. It will be necessary to plan ahead, in order to gradually implement beach protection or regeneration actions, or to develop types of "sun and sand tourism without sand". The example of Puerto de la Cruz (Tenerife) or the more recent bathing area in the Barcelona Forum enclosure, are examples of adaptation of the traditional tourism use of the coast to beachless environments.

11.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

11.7.1. Recent variations in sea level

In relation to changes in sea level (figure 11.21), data from tide gauges and from field data indicate that in the last 150 years, the rise in MSL has been around 1 mm/year (Mörner 2003), but "models of glacial loading" (Peltier and Tushingham 1989; Lambeck *et al*. 2003) enable it to be estimated at between 1.8 and 2.4 mm/year. Fundamentally based on these latter data, the predictions of rises in sea level for the next 100 years (year 2100) published by the IPCC have varied from values of 50-95 cm (IPCC 1998) and 23-49 cm (IPCC 1999) to 13-68 cm (IPCC 2001). Compared with these relatively alarmist estimates, the predictions by the INQUA – Sea Level Change and Coastal Evolution Commission, in their reports from 1993 to 2003 range from 10 to 20cm at the most. But in any case, the most interesting fact is that no acceleration of the rise in sea level has been recorded in the last 100 years.

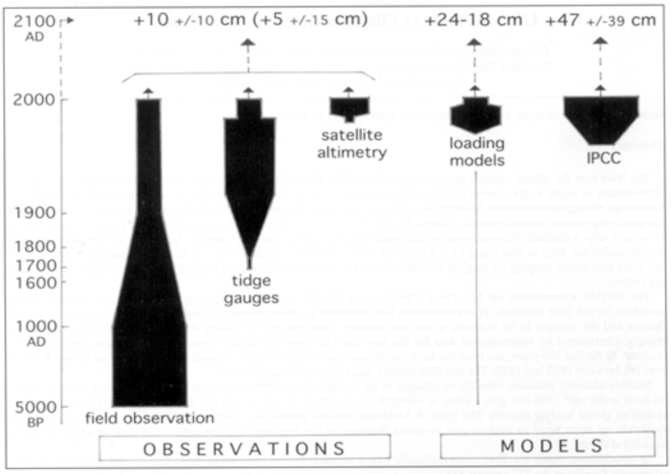

Fig. 11.21. *Means or techniques for recording or estimating changes in sea level, and for making predictions for the next century (Mörner 2003)*

The first satellite data (GEOSAT) on variation in MSL between 1986 and 1988, were not sufficiently accurate but, following the TOPEX – POSEIDON mission, the records improved (figure 11.22) and between 1993 and 1996 the level remained stable, with a noise of ±0.5 cm. Between 1997 and 1998 big oscillations in global sea level were recorded, coinciding with ENSO episodes (*El Niño Southern Oscillation*). Between 1998 and 2000 the register is irregular, showing no clear trend, but there is a possible small rise of less than 0.5 mm/year between 1999 and 2000.

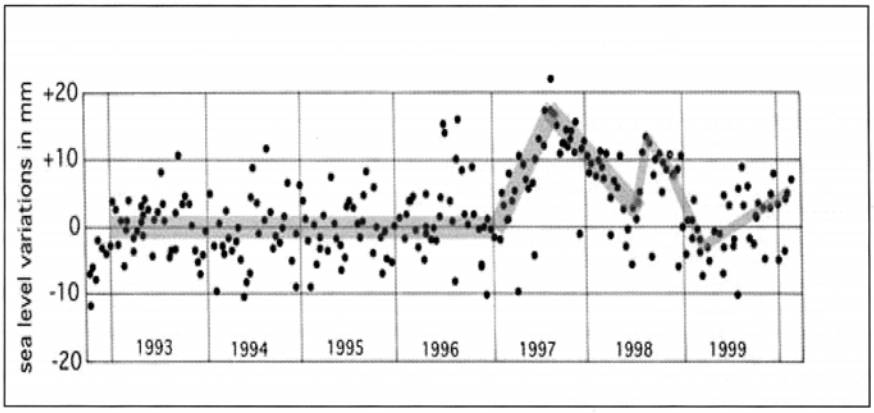

Fig. 11.22. *Measurements of variations in MSL by the TOPEX-POSEIDON satellite (Mörner 2003)*

11.7.2. Driving factors; Holocene climatic variations

The current Holocene Interglacial period (last 11,000 years) corresponds to a warm period which, until recently, was considered to be stable, especially when compared to the extreme variability of the last glacial period. Studies in the last decade, however, have revealed quite a different picture.

Ice cores in Greenland (GRIP, GISP) enabled Dansgaard *et al*. (1993) to recognise climate changes at a scale of thousands of years during the last glacial period, with temperature variations which Bryant (1997) establishes at between 6 and 7º C. Subsequently, Bond *et al*. (1997) recognised these oscillations in oceanic drillings in the North Atlantic, and extended them to the present time. They were less pronounced (only 2º C) during the Holocene, recognising cold events (Bond Events) of little duration (100-200 years) with a periodicity of between 1 and 2 Ka, the peaks of which date from 10.3 Ka, 9.5 Ka, 8.2 Ka, 5.9 Ka, 4.3 Ka, 2.8 Ka and 1.4 Ka (calibrated ages).

Different causes have been suggested for these climatic oscillations: variations in orbital parameters (cycles of 900 years, Loutre *et al*. 1992), oscillations in the ocean-atmosphere system (cycles of 1500 years, Bond *et al*. 1999), changes in solar activity (cycles of 2500 years, Stuiver and Reimer 1993) and fluctuations in the thermohaline circulation in the North Atlantic (cycles of between 550 and 1000 years, Chapman and Shackleton 2000). This climatic variability appears to of a global nature and must surely affect the climate in the North Atlantic (Arz *et al*. 2001).

In the Atlantic-Mediterranean connecting area, Cacho *et al*. (1999, 2001 y 2002) studied core drills in the Gulf of Cadiz (off the Huelva-Cadiz coast) and the Alborán Sea (off the Almeria coast), recognising events of sea surface temperature (SST) rise of a magnitude that is not well established and a periodicity of 750 years and harmonics. In Alborán, they are recognised at 8.2, 5.36 and 1.4 Ka, but in the Gulf of Cadiz, only at 8.2 Ka. Regardless of the exact value of the oscillations, there is evidence of a general cooling tendency during the Holocene in the Northeast Atlantic and in the Mediterranean (Marchal *et al*. 2002), which could be related to the transition of the hypsithermal interval (9-5.7 Ka BP) to the Neoglaciation (ca. 5.7 a = Ka BP).

11.7.3. Coastal response

Study of coastal units on the Mediterranean coast and in the Gulf of Cadiz has highlighted the existence of sedimentation and erosion trends which, once dated and calibrated, reveal a cyclical character comparable to the previous ones, observed at different temporal scales.

Decadal scale. The beach ridges are associated in double pairs separated by throughs or *swales* of greater range, and this grouping is called a *set*. In ideal conditions, the dating of mollusc valves collected in successive swales allows the time required for their accumulation to be estimated. In practice, only some of these swales can be dated, so that the time lapse separating them is divided by the number of ridges accumulated between both of them, to calculate the average accumulation time of a ridge.

In the Gulf of Cadiz (Doñana Spit bar) the duration of a set is 400 years (figure 11.23), that is, each ridge accumulates in about 100 years (Zazo *et al*. 1994), whereas in Roquetas (Mediterranean coast of Almeria) the corresponding values are 45 and 11 years (Goy *et al*. 2003), (figure 11.24). This difference is presumably due to differences in the tidal range, wave energy, sediment size and availability, without excluding the lower degree of conservation of the sand ridges formed on the coast of the Gulf of Cadiz. According to previous authors, the cyclicity of Roquetas appears to be related to simple sunspot cycles and with the NAO oscillation, whereas in Doñana, it is considered to be linked to secular sunspot cycles.

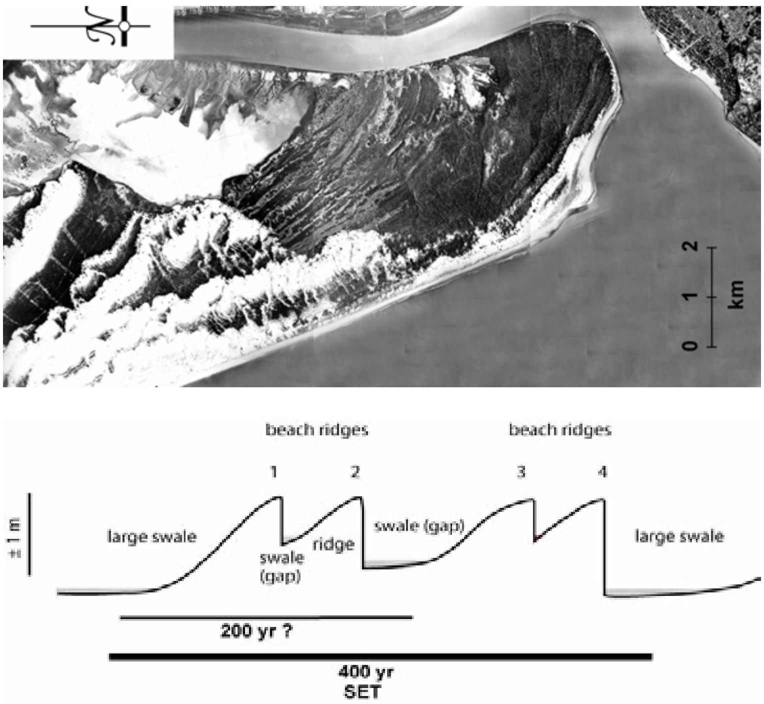

Fig. 11.23. *Doñana Spit (Cadiz) and accumulation diagram for approximately 100 years (Zazo et al. 1994)*

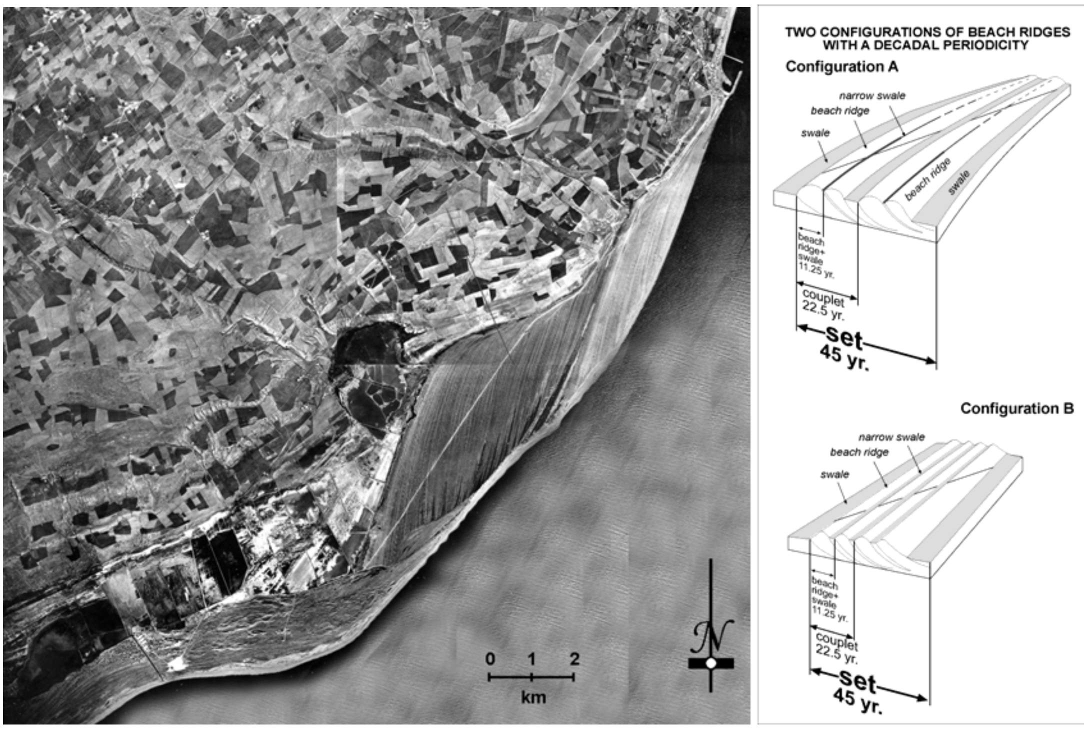

Fig. 11.24. *Roquetas Spit bar system(Almeria coast) and accumulation diagram every 11 and 45 years (Goy et al. 2003)*

In the recent records made by Rodríguez-Ramírez *et al*. (2000) on the litoral spit bars in Huelva for the last 40 years, the formation of very small (figure 11.25) beach ridges has been related to intensification of SW winds (storms), negative NAO index and a lower number of sunspots (figure 11.26).

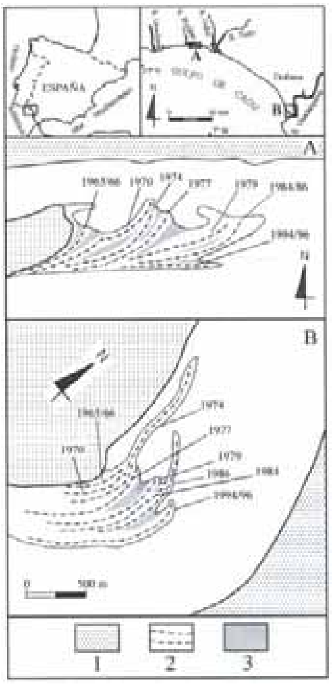

Fig. 11.25. *Beach ridges and swales. Growth chronology between 1956 and 1996 for the beaches of El Rompido (A) and Doñana (B) in the Gulf of Cadiz (Rodríguez Ramírez et al. 2000)*

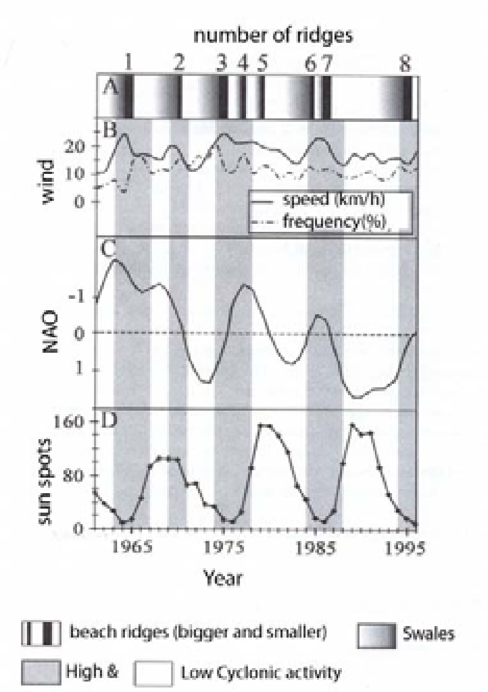

Fig. 11.26. *Relationship between the formation of beach ridges with sunspots, Negative NAO index and intense SW winds (Rodríguez Ramírez et al. 2000)*

Secular scale ("centennial"). The trend towards progradation, that is, coastal advance, generalised on the previous coastlines, is interrupted periodically (figure 11.27). Erosional surfaces have been identified resulting from the increased intensity of storms together with a small rise in MSL, estimated at between 0.5 and 0.8 m (Goy *et al*. 2003). The duration of these episodes is very short (a few decades), but they cause very visible effects in the organisation of the morph-sedimentary units. Between 6000 and 3000 BP the erosion episodes took place approximately every 600 years, but since 2700 BP the interval was reduced to 400 and 200 years. This change coincided with a relevant modification in the regime of prevailing winds, which changed from Westerlies to Southwesterlies, modifying the longshore drift and causing erosion (Zazo *et al*. 1994, Borja *et al*. 1999, Dabrio *et al*. 2000, Goy *et al*. 2003).

At a *scale of thousands of years*, episodes of coastal progradation can be recognised which last between 1200 and 1500 years and which Zazo *et al*. (1994) termed "H" units: units of prograding spits that make up the spit bar systems. The have been recognised in the spit bars of Piedras, Punta Umbría and Doñana (Huelva), Valdelagrana (Cadiz), Calahonda (Granada, Lario *et al*. 1999), Roquetas (Goy *et al*. 2003) and Albufera de Alcudia (Mallorca, Goy *et al*. 1996). They are separated by intervals during which no beach ridges accumulated, or, if they did so, they were smaller and were deposited at topographically lower elevations, which is interpreted as the result of a transitory drop (of secular duration) in the estimated MSL of between 0.5 and 0.8 m, together with reduced storm activity. These ridgeless episodes, also called *gaps,* were formed in a short period of time, between 200 and 400 years. Those of approximate ages of between 5.5, 2.7 and 0.7 Ka are easily recognisable, and that of ~4.2 Ka is much more difficult to obseve.

The *gaps* or interruptions are interpreted as the result of periods of extreme aridity within the general trend towards aridity. These conditions appeared to be dominant, with prolonged periods of positive NAO and less intense entry flow of surface water from the Atlantic into the

Mediterranean (Goy *et al*. 2003). Comparing these results with the data on the Alborán Sea and the North Atlantic obtained with the use of other *proxies*, it can be seen that they coincide with Bond cold events at 5.9, 4.3 and 2.8 Ka and at least one (5.36 Ka) of the surface sea water cold events (SST) described by Cacho *et al*. (2001).

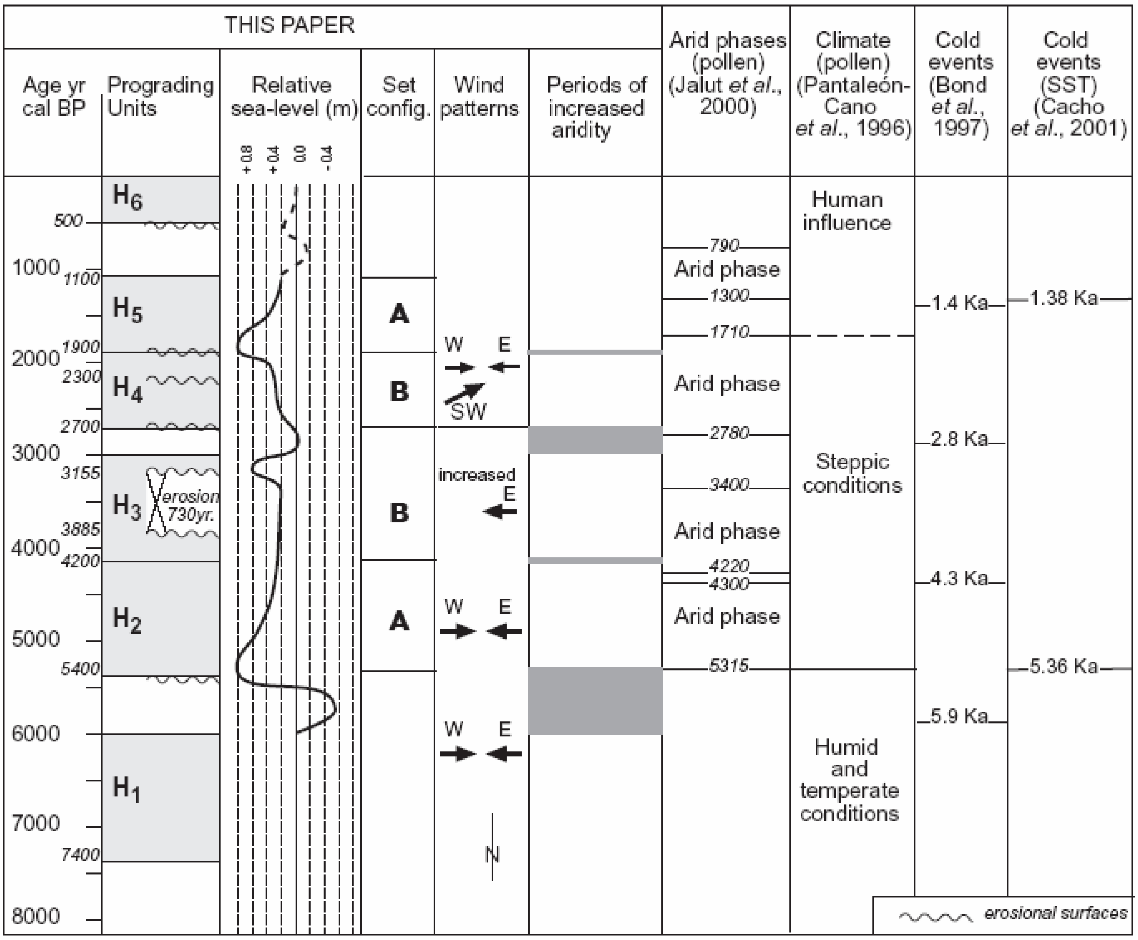

***Fig. 11.27.** Progradation tendency interrupted by erosional surfaces resulting from increases in the intensity of storms and small rises in MSL (Goy et al. 2003)*

11.7.4. Interactions

The treds and cyclicities described overlap, each one with a specific periodicity, and in theory, they ought to produce harmonics and interferences. The period of the cycles, however, is not very constant and has a very appreciable margin of error at human life scale. The most general cyclicities involve changes in the atmosphere-ocean system and are at millenial scale, with periodicities of between 1200 and 1500 years. This is seen in the so-called Bond events, and is manifested in the North Atlantic by cold periods (short, with a duration of centuries). According to recent records in Roquetas (figure 11.27), we are about to experience one of those events which, at our latitudes (Atlantic-Mediterranean connecting area), would involve a drop in sea level, extreme aridity, greater frequency and intensity of Saharan winds and a prolonged positive NAO index. In theory, this effect is the opposite of what is usually attributed to anthropic action (global warming and a rise in sea level).

Furthermore, in relation to the cyclicity of 600 years (or somewhat less in the last two millennia), we approach one of the short NAO periods (of around two centuries), predominantly negative, which cause an increase in precipitation and in sea level and a radical increase in coastal erosion, marking the end of the progradation phases (in this case, the H6). In theory, these effects would be added to those triggered by human-induced climate change, which is usually invoked, and relative sea level would rise.

In theory, both cyclicities could coincide and their relative effects could be cancelled out. The margin of variation of each one, however, is wide enough to present great uncertainty with regard to what is really occurring.

With all this in mind, and in order to consider adaptation and mitigation strategies, two scenarios of a rise in MSL are recommended for the end of the century, one which is considered “most likely”, of 50 cm (coherent with most of the projections and with data on the Holocene) and another one of 1 m or “pessimistic scenario”. The latter corresponds approximately to the maximum predictions of several models and also to the rises detected at different points of the coast around 5500 and 2000 years ago. The chances of this scenario materialising are smaller, particularly on the S and E coasts.

11.8. DETECTING CHANGE

11.8.1. Driving factors

Detection of change in the driving factors or agents (temperature, precipitation, winds, waves, currents), will need to be based on the corresponding meteorological or oceanographic observations. In the specific case of the coastal area, the regular measurement of sea water level and temperature is of interest, at a sufficient number of points (horizontally and vertically). Also of interest are continuous measurements of wind speed and direction, and of swales and circulation.

The most important point, common to all the aforementioned variables, is the continuity and accuracy of the records. Otherwise, it will not be possible to reliably detect the “weak” sign of climate change at decadal scale.

11.8.2. Geomorphlogical response

The most sensitive elements to changes in coastal dynamics are beaches and coastal lowlands. The detection of changes in the area, shape or position of these, with the use of profiles with regular or continuous follow-up, based on remote sensing techniques, including aerial or satellite images, can be used to detect variation trends in sea level or other driving factors, which are difficult to detect in a direct way.

11.8.3. Response by the ecosystems

In an analogous manner, monitoring systems of variations in the area or position of particularly sensitive ecosystems, such as coastal wetlands, can be set up. Some properties of coastal waters (temperature, salinity, etc.), as well as the nutrient content of these, could be affected by local changes in climatology. Saline penetration into terrestrial aquifers is an indicator of noteworthy socio-economic interest, although it is difficult to accurately predict.

11.8.4. Socio-economic response in uses and management thereof

As we have pointed out, the main resources to be considered are of the “non-consumable” type, such as beaches, dunes and wetland ecosystems. In recent years, changes in uses in these units have been almost exclusively determined by types of human activity that do not depend on climate change. This will probably continue to be the determinant factor in the coming decades. Monitoring of these changes can be done easily through remote sensing, based on aerial or satellite images.

11.9. IMPLICATIONS FOR POLICIES

Most of the problems described here as likely consequences of climate change are also caused by unrelated human activities. From the point of view of coastal policy, it is of interest to deal with these problems, not with climate change itself. We therefore present a series of recommendations for a coastal conservation, protection and management policy which will be useful, not only as actions for the prevention and mitigation of the impact of climate change, but also in the event that this change were to occur much more slowly than expected or did not occur at all.

11.9.1. Anticipation in decision-taking

Although there are solutions (whether these be of the structural or non-structural type) for practically all the problems identified, it is impossible to act along the whole coast in a sufficiently short period of time to deal with them, albeit due to the lack of sufficient financial resources. It is therefore very important to take the corresponding decisions in due time. In the first place, these decisions should involve those interventions that will be beneficial in any case (many of these have already been described), regardless of the magnitude and rhythm of climate change.

11.9.2. Policies "from above" or participatory policies

The main problems described can be divided into two main categories: a) those relating to the stability of beaches and coastal lowlands comprising incoherent materials; b) those relating to floodable coastal lowlands, wetlands and intertidal areas. Both types of coastal units are mostly of public ownership, but the displacement of these could also affect private property.

In the case of measures only affecting publicly-owned property (for example, actions aimed at maintaining confined beaches), it is possible to implement policies “from above”, although it is considered very convenient to include all stakeholders in the decision-making process (Central Administration, regional autonomies, municipalities, neighbouring owners, the production sectors affected, conservationist groups), in order to establish agreements, both with regard to the intervention priorities (and investment) and to the technical solutions to be adopted.

When the measures affect private property (for example, abandonment strategies aimed at permitting wetlands to migrate inland), measures of a participatory nature become especially necessary, because the corresponding compensation will have to be provided for.

11.9.3. Intervention criteria

The intervention criteria to be applied derive from the previous point and should consider: a) the potential importance (social, economic, ecological) of the problem; b) the possibility that the measures to be applied might be unnecessary or even counter-productive if the change does not occur in the time period or with the magnitude predicted; c) imminence of the risk or urgency to intervene: d) intervention costs.

It is initially believed that priority should be given to policies that deal with the aforementioned serious problems, with measures that would be of use in any case, regardless of the rhythm of future changes (for example, actions in river basins aimed at ensuring regular sediment supply to the coast, in order to contribute to the stability of beaches and deltas). If, as a consequence of the establishment of monitoring systems, particularly rapid changes are detected in some areas, it will be necessary to act with greater urgency.

11.10. MAIN RESEARCH NEEDS

The research needs identified are related, on one hand, to knowledge of climate variations in the recent past (approximately in the last 10,000 years) and to the reflection of these change in relative sea level and the morphodynamic processes that have affected the coast. Available data indicate that approximately 5,500 years ago, conditions existed that are comparable to those predicted for the end of the century. Detailed knowledge of the evolution of past processes (if possible, with annual or decadal resolution) would significantly help to increase the accuracy of the projections. More in-depth knowledge is also needed of the effects of the climate changes, in particular in MSL, and of other driving factors such as swale, together with the corresponding morphodynmic change, that could take place in coastal ecosystems and in human activities.

Apart from the need for a more in-depth understanding of the processes at play, there is a need for data on the different parameters intervening therein, which at present are quite scarce. This requires the implementation of systematic monitoring and data collection systems in relation to these parameters (in time and in space) which, although they do not strictly constitute research actions, will allow for the establishment of empirical relationships or the design and validation of models.

11.10.1. Driving agents/factors and local climate

It is of particular interest to learn more about the effects of climate change upon the wind and swale regimes and the circulation patterns affecting each area.

11.10.2. Morphodynamic response of the coast

The units most sensitive to the morphodynamic changes that affect the coast are beaches (and associated dune fields) and other coastal lowlands. Deltas are of particular interest and, due to subsidence, are undergoing a relative rise in MSL. In order to increase knowledge of the factors determining these changes, and therefore, prediction and response capacity in relation to these, there is a need to develop and apply models that simulate the behaviour of the main types of beaches (and sand ridges in general), and to establish systems for regular monitoring of the changes.

11.10.3. Response of ecosystems

The most important ecosystems on the coast are constituted by dunes, marshlands and intertidal areas. We must seek a more in-depth understanding of how these have responded to past climate changes (Holocene), and establish systems for monitoring the changes they might be undergoing at present.

11.10.4. Property, resources and uses in coastal areas and estuaries

The main need in this case involves an inventory of the areas that could be affected by the main types of processes described. Given that most of the potential problems derive from an increase in relative sea level or from the effects of storms, there is a great need to avail of sufficiently detailed mapsor Digital Elevation Models (decimetric or centimetric vertical resolution) of the environments that might be affected. This maps or models could be used to demarcate the areas and elements at risk and to quantify the areas and values affected.

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12. IMPACTS ON NATURAL HAZARDS OF CLIMATIC ORIGIN

Gerardo Benito, Jordi Corominas and José Manuel Moreno

Natural disasters are defined as natural phenomena occurring within a limited space and period of time, causing disruption to peoples' lives (Olcina and Ayala-Carcedo 2002). In Spain, from 1971 to 2002, natural disasters caused material damages of over 3,400 million Euros (>110 million Euros per annum, according to the Consortium of Insurance Compensation 2003, figures expressed according to December 31st 2001 values), causing over 1,680 deaths (according to Olcina *et. al.* 2002; including the 794 casualties in the 1962 floods in Catalonia). During the last decade, coinciding with the International Decade for Natural Disaster Reduction (1990-2000), these damages have increased considerably, almost in an exponential manner (see damage statistics in Piserra *et al.*, this volume), with material damages of over 515 million Euros and 480 fatalities (according to the Consortium of Insurance Compensation 2003 and Olcina *et al*. 2002, respectively). This upward tendency of damages caused by natural disasters supports the idea that extreme events associated with the effects of climate change are occurring with greater frequency. In this respect, we must disassociate the frequency and magnitude of natural disasters from the socio-economic impact and perception by the media, which, frequently, responds more to the intensive occupation of the territory (exposure to risk of property and people) and the reduced thresholds of social tolerance to natural hazards.

The climate-related natural hazards with the greatest impact in Spain, affecting terrestrial areas, include floods, droughts, landslides, avalanches, lightening, forest fires, gales, blizzards, hail, storms, cold spells, heat waves and subsidence affecting buildings and civil engineering works. The greatest losses of human life in the last five decades have resulted from flooding (1,525 fatalities), cold spells (>40 fatalities), heat waves (>300 fatalities), landslides (>39 fatalities), avalanches (>17 fatalities), wind storms (>15 fatalities), and lightening (>2,100 fatalities). This chapter will deal with the possible impacts of climate change in relation to certain natural disasters, in particular floods, landslides and avalanches, lightening and forest fires.

12. IMPACTS ON NATURAL HAZARDS OF CLIMATIC ORIGIN

A. FLOOD RISK

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ABSTRACT

The characteristics of climate and relief on the Iberian peninsula favour the generation of floods. In Spain, these floods have historically had serious socio-economic impacts, with over 1,525 fatalities in the last five decades. Floods are the consequence of abnormal weather at a limited spatial-temporal scale and, so far, cannot be simulated with the physical models that predict the different scenarios of future climate change. Possible scenarios of the impact of climate change on flood regimes can be diagnosed through the use of millennial scale relationships of flood response to changes in climate, these obtained from geological and documentary data.

In Atlantic basins, the generation, duration and magnitude of floods are very much associated with changes in winter rainfall. Palaeoflood and documentary flood records show greater frequency of ordinary and extraordinary events during the initial and final phases of cold periods such as the Little Ice Age (1550-1850). In the instrumental period (1910 to the present), Atlantic rivers underwent a decline in the frequency of extraordinary floods, although the magnitude of the most catastrophic floods has remained the same, despite the flood control effect of reservoirs. This upward trend of hydrological variability is expected to continue in the forthcoming decades (medium level uncertainty) if we take into account the intensification of the positive phase of the North Atlantic Oscillation (NAO). In the case of rivers Duero and Ebro, peak discharges might be affected by the sudden snowmelt resulting from sudden variations in winter and spring temperatures.

In Mediterranean basins, past flood series indicate that extreme floods occur during periods of high irregularity of both seasonal and annual rainfall. In recent periods (the seventies and eighties) an increase has been observed in intense rainfall episodes, some of which have caused extraordinary floods. These recent floods reached maximum discharges above those recorded in gauging stations in the first half of the 20th Century (prior to the construction of reservoirs). In this sense, existing data indicate (high uncertainty level) that the temperature rise could increase the irregularity of the flood and drought regime and cause the generation of flash floods in Mediterranean basins.

The areas vulnerable to floods are located close to town centres and tourist resorts (particularly in the Mediterranean). There has been a considerable increase in these vulnerable areas as a consequence of increased exposure resulting from the spread of urban areas, new construction works (e.g. roads, railways, canals) and from human activity close to water courses. The socio-economic sectors that could be affected by increased flood hazards are tourism, transport and distribution, and, to a lesser degree, the insurance sector.

The main adaptation options are based on better understanding of the preventive measures, aimed at improving land planning, and on prediction systems currently operating in some basins.

Among the main research needs, we can highlight the reconstruction of past flood series, analysis of instrumental gauging series, and the development of coupled regional climate-hydrology models that can provide reliable scenarios of hydrological extremes, considering the particularities of the Atlantic and Mediterranean basins.

12.A.1. INTRODUCTION

Given the climatic, topographic and geologic conditions of the Iberian Peninsula, flooding episodes and prolonged periods of drought constitute normal hydrological phenomena with which society has to live. Floods are the natural risk with the greatest economic and social impact that can be generated in a short space of time (hours or days), although, if we are dealing solely with economic losses, drought impact in crops and losses in hydroelectric power generation can lead to higher economic costs (Pujadas 2002). Since the floods in Valencia in 1957, there has been, on average, one serious flood every 5 years (CTEI 1983). The 10 most important events with regard to compensation paid out by the Consortium of Insurance Compensation (CCS) have occurred recently, six in the 1980s and four in the 1990s (see see Chapter 15).

The impact of climate change resulting from the greenhouse effect in relation to flooding constitutes one of the main uncertainties of all the reports drafted to date by international bodies. The latest report written by the IPCC (IPCC 2001) indicates that the increases in greenhouse gasses and aerosols in the atmosphere will cause an increase in climatic variability and extreme events in many parts of the world. In Europe, the frequency and severity of floods could increase, especially in the largest river basins in central and Western Europe, due to the concentration of rainfall in winter and spring months (IPCC 1996). Likewise, increased temperatures at the end of spring and during summer could lead to an increase in torrential rainfall of a convective nature in small basins and, therefore, to increased risk of flash flooding, especially in mountain areas and in Mediterranean regions.

The Acacia Report (Parry 2000) indicates that the main risk in southern European countries derives from flash floods caused by torrential rains. This report informs that for the year 2020, abnormally hot summers, like the one that occurred in 2003, will be between four and five times more frequent than at present. In spite of all these conjectures, in reality none of the global or regional atmospheric circulation models are capable of generating reliable scenarios of the changes to be expected in relation to extreme events, and these statements are based on the idea that climate change will alter the whole volume of monthly rainfall in the same proportion, without considering rainfall concentration over short time periods (for example at hourly or daily timescales).

12.A.2. CLIMATIC SENSITIVITY

12.A.2.1. Present climatic sensitivity of floods

The magnitude and frequency of floods vary in different drainage basins, depending on their morphometric variability, network scale and, in particular, the type of circulation patterns generating the floods (Benito *et al*. 1996; 1997; Fig. 12.A.1). During winter, flows from the west and northwest dominate, and are closely related to a high frequency of zonal circulation at high altitude. This situation conditions to a greater degree the areas affected by Atlantic air masses, mainly the rivers Duero and Tagus and basins in Galicia and Cantabria. The latter areas, however, are more influenced by intense rainfall caused by northern advection, which also affects the headwaters of the Ebro and the Duero. The Guadiana and Guadalquivir basins, although affected by these disturbances, register the most noteworthy episodes when circulation acquires an intense southern component, which is usually associated with the presence of low pressure in the Gulf of Cadiz bringing very wet flows from the southwest.

At the end of winter, when the circumpolar vortex becomes weaker and the setting of an undulating circulation pattern occurs (a change on main flow towards south and southwesterly directions takes place, presenting their higher frequency at the end of spring. This type of circulation is responsible for large volumes of rainfall in the East and Southeast of Spain, mainly in the Mediterranean basins of the Júcar, Segura, Ebro and the Eastern Pyrenees and southern rivers. In Mediterranean basins, the advance of air masses from the Atlantic that are relatively colder than the sea can increase instability and facilitate the formation of convective systems. The highest number of cold pools is generated during this season (Llasat and Puigcerver 1990), occurring mainly in the western part of Spain (Llasat 1991) and which can be associated in some cases with moderate rainfall. Some rivers in Spain also present a second flow peak during spring, due to sudden snowmelt that occurs mainly at the riverheads in mountain areas (Fig. 12.A.1).

Summer is characterised by scarce rainfall throughout much of Spain, especially to the south of the Cantabrian Range. In northern Spain (Galicia, Cantabria and the Basque Country), however, on exceptional occasions there can be flooding associated with northern flows and with the presence or lack of cold pools. Intense, short-lived rainfall episodes affect usually the Pyrenees and the Catalonian coast at this time of year, responsible for flash floods in *arroyos* and ephemeral streams. The contribution of these rainfall events to the hydrological budget of these mountain catchments is nevertheless small, due to the short time duration of these rainfall events and small catchment areas. The total rainfall contribution of these summer events to the basins is low, due to their short duration and small area.

Finally, during autumn, there is an increase of the west and northwest circulation, as well as of the southwest type. Situations from the southeast at low atmospheric levels and the southwest at high altitude (associated with the presence of a high altitude trough or cold pool), with advection of very hot and humid air at low levels, are very favourable for the development of organised convective systems, which generate floods (Jansà *et al* 1996). These systems affect mainly the Mediterranean coast, leading to events that generate floods in rivers of the Eastern Pyrenees, the Júcar and Segura basins and also in the Ebro basin and southern rivers. In the case of the Mediterranean rivers that drain the Iberian Range (Júcar, Segura and Turia), the highest peak discharges are recorded during this period. Indeed, the average discharge of these rivers can be multiplied by up to 11,000 times during the largest floods (Masach 1950).

Analysis of the series of annual maximum discharges recorded at gauging stations indicates a decrease in the peaks of ordinary floods over the last 40 years (Fig. 12.A.2). This decrease in peak discharge is partly due to the construction of dams, built mostly between the 1950s and 1960s, currently exceeding one thousand dams (1,133 including weirs), with a storage capacity of over 56,000 hm^3. This flood control effect of reservoirs, however, is insufficient in the case of the largest floods, such as those recorded in Mediterranean basins in 1982 and 1987, or in the Atlantic basins in the year 1979. As can be seen in Figure 12.A.2, these floods presented the highest peak discharges in the systematic gauging records (last 50 years). It is evident that hydraulic infrastructures have modified the natural trends of maximum discharges, which hinders hydroclimatic analysis of instrumental series. In some cases, the series of maximum discharges have been restored to their natural regime to eliminate the noise artificially caused by the inclusion of the reservoirs, although there are very few studies of this type in Spain. We should, therefore, be somewhat cautious when interpreting the tendency of flood discharges recorded in the last 30 years in regulated rivers, in relation to the effects of climate change.

In the Atlantic basins, flood generation, duration and magnitude, are closely related to changes in winter rainfall. Although the relationships between mean discharge, rainfall and peak discharge are not straightforward in these basins, the extremely wet years (Fig. 12.A.3), correspond to years with high peak discharges. The heaviest rainfall in the Atlantic basins occurs when the zonal circulation is displaced towards lower latitudes (35-45º N) and the Occidental Iberian Peninsular Coast is affected by the entry of successive frontal systems, thus generating heavy and persistent rainfall in the basins of the Duero, Tagus, Guadiana and Guadalquivir rivers. A southerly wet air flow associated with an undulating flow circulation pattern is often responsible for intense rainfall over the Guadiana and Guadalquivir basins. In the Mediterranean basins, the relationships between rainfall and floods do not respond to any specific pattern, and climate–flood relationships are, therefore, difficult to establish.

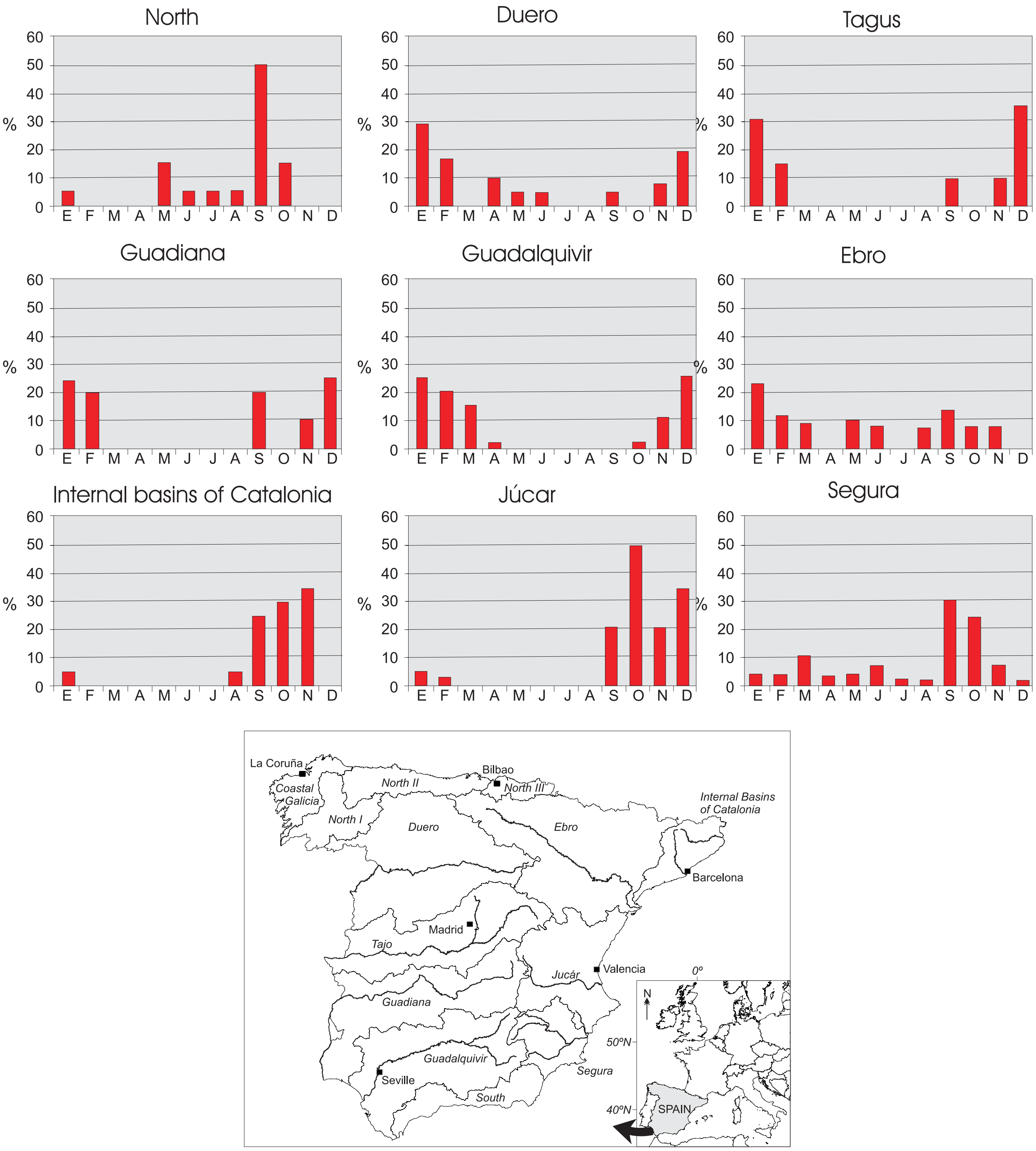

__Fig. 12.A.1.__ Upper figure: Monthly distribution of historic floods in different river basins (after Benito et al. 1996). Lower figure: Spanish administrative watershed distribution.

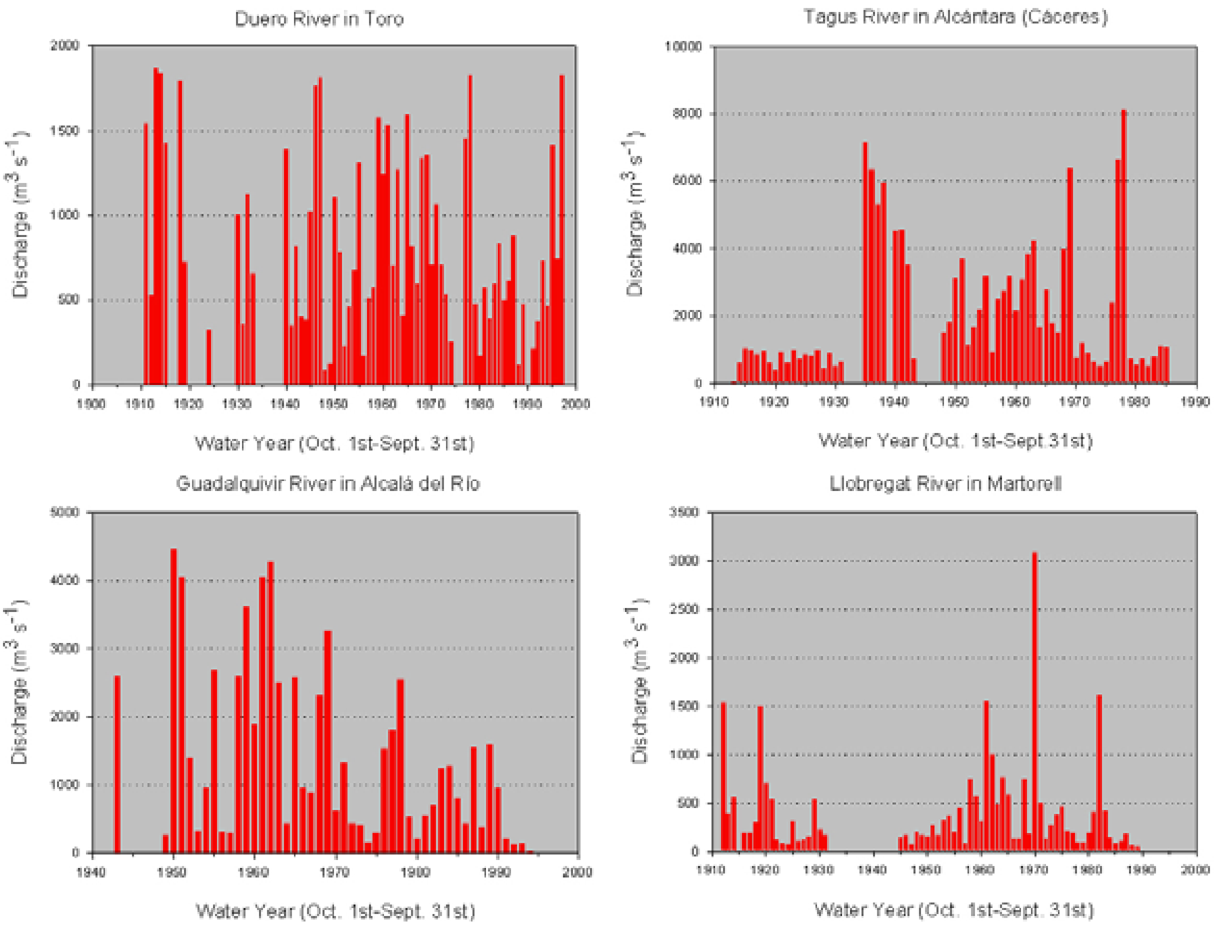

Fig. 12.A.2. *Annual series of flood discharge in the rivers Duero (Toro), Tagus (Alcántara), Guadalquivir (Alcalá del Río) and Llobregat (Martorell).*

12.A.2.2. Effects of climatic variability on hydrological risks based on past series

Alternating warm and cold periods has been described for the last thousand years (e.g. the Medieval Warm Period, around AD 900-1200 and the Little Ice Age, around AD 1550-1850, Flohn 1993). In the same way floods and droughts have also varied, in response to these climate changes. Geologic and documentary records make possible the reconstruction of the frequency and even the magnitude of these extreme events. Geologic records are based on studies of the sediments deposited by rivers during floods (Benito *et al*. 2003a) and they enable us to go back in time up to 10,000 years ago (the Holocene). With regard to documentary records, archives of public and ecclesiastical administrations, at country, regional or local level are used. Three types of registers are obtained from these documentary sources: i) complete and continuous series from the 16th Century till present time; ii) discontinuous series between the 14th and the 15th Century, and iii) occasional events since classical times through the use of Greco-Roman and scattered Christian medieval and Arab documents (Benito *et al*. 2004; Barriendos and Coeur 2004). In all cases, it can be seen that floods are not evenly distributed in time, rather there are periods in which an abnormal concentration of atmospheric circulation patterns generate extreme events and respond to changing climatic situations.

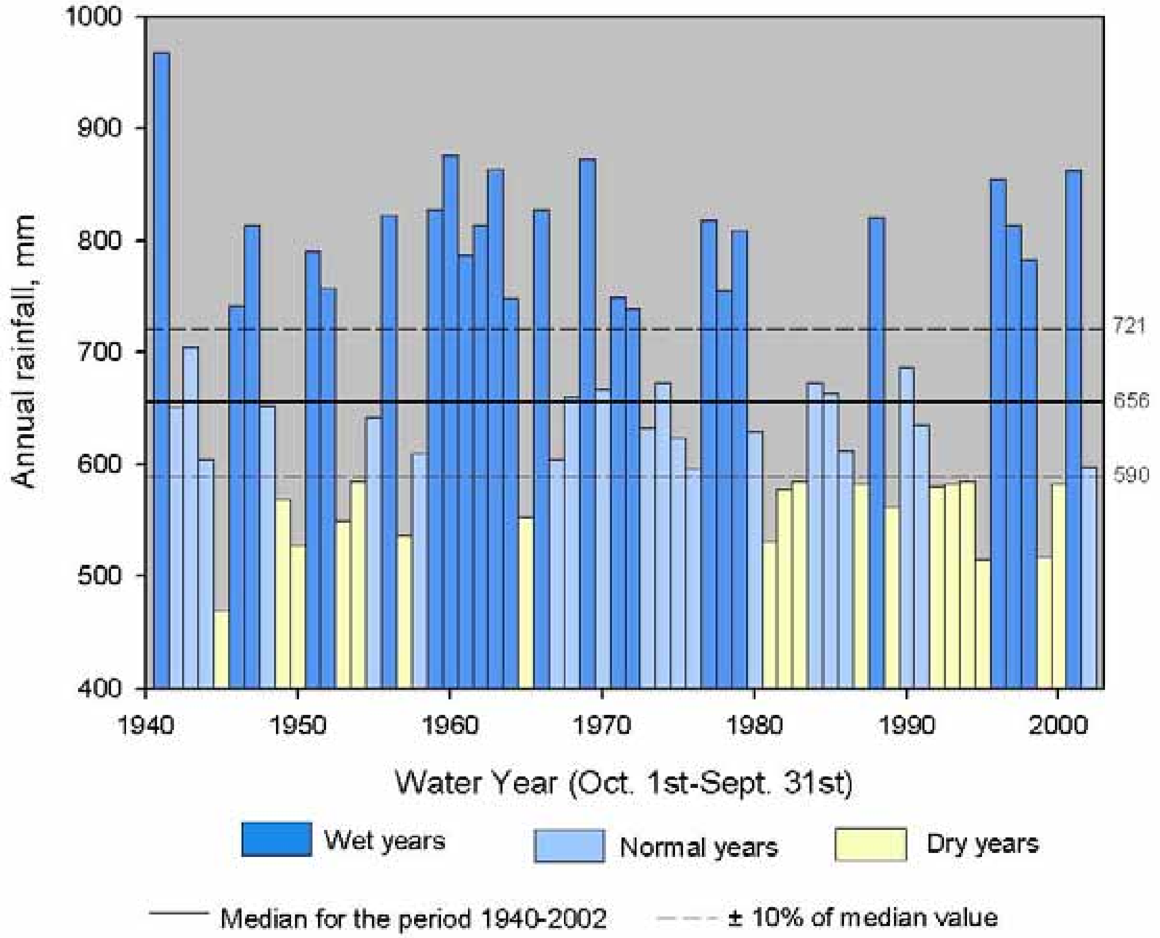

Fig.12.A.3. *Temporal variation in annual rainfall (mm) in mainland Spain and classification of years according to their deviation from the mean (656 mm) for the period 1940/41 - 2002/03 (hydrological year – October to September).*

It is generally assumed that for the past 3,000 years the general circulation of the atmosphere has presented similar characteristics to those at present and it is, therefore, in this period that analysis of climate–flood relationships is of greatest interest. During this period, hydrological response was affected both by climatic variability and human activities, especially during the last 1,700-2,000 years with the establishment of agricultural societies that set in motion intense deforestation processes. It is evident, however, that the generation of floods in medium-sized to large-size basins responds to excessive rainfall in these basins, with a moderate or less important role played by human activity in terms of the infiltration capacity of soils.

Palaeoflood records show an abnormal concentration of extreme events in different basins in the Mediterranean environment from 2860 to 2690 years B.P. ("before present"), that is, between 850 and 550 B.C. (Thorndycraft *et al*. 2004¸ Fig. 12.A.4). This period precedes or is close in time, to a cold and wet phase around 2,650 years ago (van Geel *et al*. 1999), which is associated with variations in the emission of solar radiation. In the River Llobregat, the magnitude of the floods generated in this period practically doubles those recorded in the 20th Century and can only be compared to some observed in the 17th Century (Thorndycraft *et al*. 2004; Fig. 12.A.4).

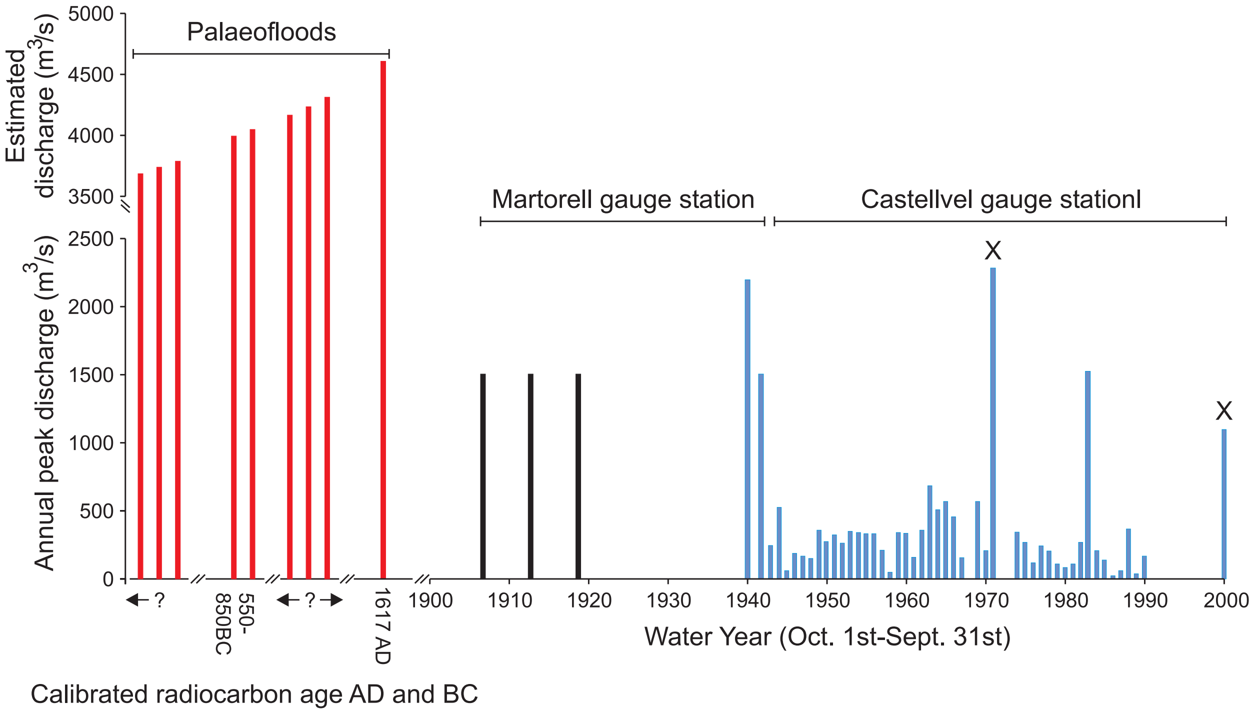

Fig. 12.A.4. *Estimated discharges of the largest floods that occurred in the last 3,000 years in the medium-lower reaches of the river Llobregat using geologic records (red), together with those recorded in gauging stations in Martorell (black) and Castellvell (blue) (modified from Thorndycraft et al. 2004).*

Sediment records of palaeofloods covering the last 2,000 years indicate an abnormally high frequency of large floods during AD 1000-1200, AD 1430-1685 and AD 1730-1810 periods. The resolution of the radiocarbon dating technique for the last 300 years is poor, and this last period could, therefore, reflect dating errors. These periods correlate in time with those obtained from documentary records, which show an increase in the frequency of floods of large magnitude in the Atlantic basins of the Iberian Peninsula during the periods 1150-1290 1590-1610 1730-1760 1780-1810 1870-1900 1930-1950 and 1960-1980 (Benito *et al*. 1996; 2003b; Fig. 12.A.5). The climatic conditions prevailing in these periods with a high frequency of floods are difficult to estimate. In historic climatology, the terms Medieval Warm Period and Little Ice Age have been used to define two secular climatic episodes involving warming and cooling, respectively, which have occurred in the last 1,000 years. However, a number of recent studies show that the start and duration of these periods vary regionally.

The study of floods and climate during the Little Ice Age (LIA) in the Iberian Peninsula has been studied also using historical documentary sources. These studies indicate an intense climatic variability, characterised by periods of increased frequency of torrential rains, reflected in catastrophic flooding, as well as by an increased frequency of prolonged droughts. This abnormal behaviour usually lasted for 30 or 40 years (Fig. 12.A.6), being the periods of 1580-1620 and 1840-1870 the ones where the highest flooding severity was registered (Barriendos and Martín Vide 1998). Regarding droughts, it is more difficult to define distinct periods due to their complex spatial distribution, but they were clearly more frequent in the middle 16th (1540-1570) and 17th centuries (1625-1640), less severs in 1750-1760, as well as between 1810-1830 and 1880-1910 (Barriendos 2002). The existence of periods with flood frequency together with droughts should also be mentioned. To date only one such period is known, between 1760 and 1800, but its effects spread throughout much of Western and Central Europe, with a clear impact on agricultural production and even social crises in different countries (Barriendos and Llasat 2003).

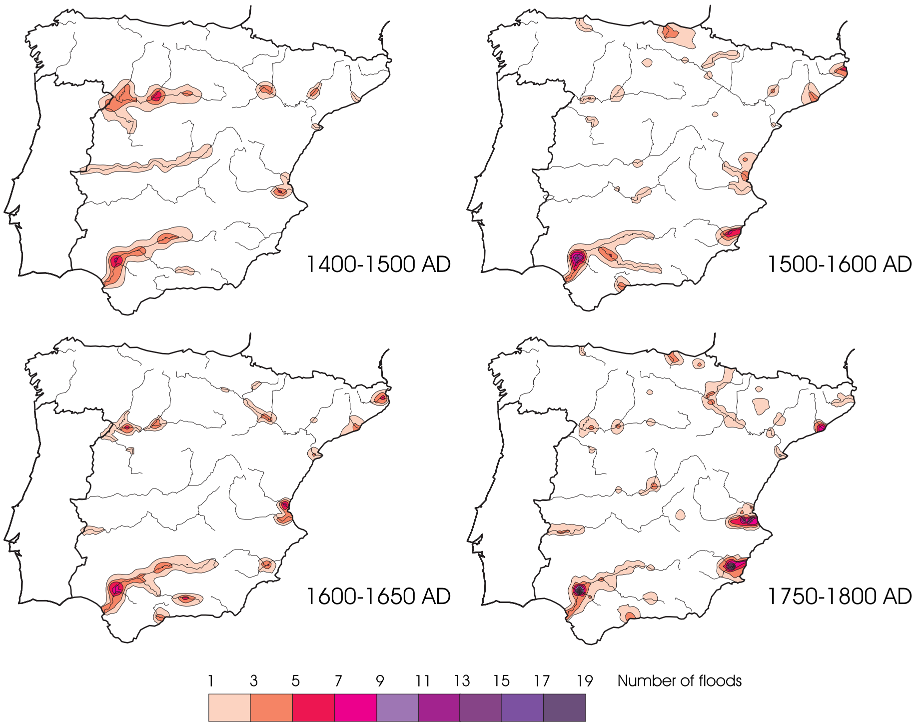

Fig. 12.A.5. *Distribution of historic floods in Spain during different periods (according to Benito et al. 1996).*

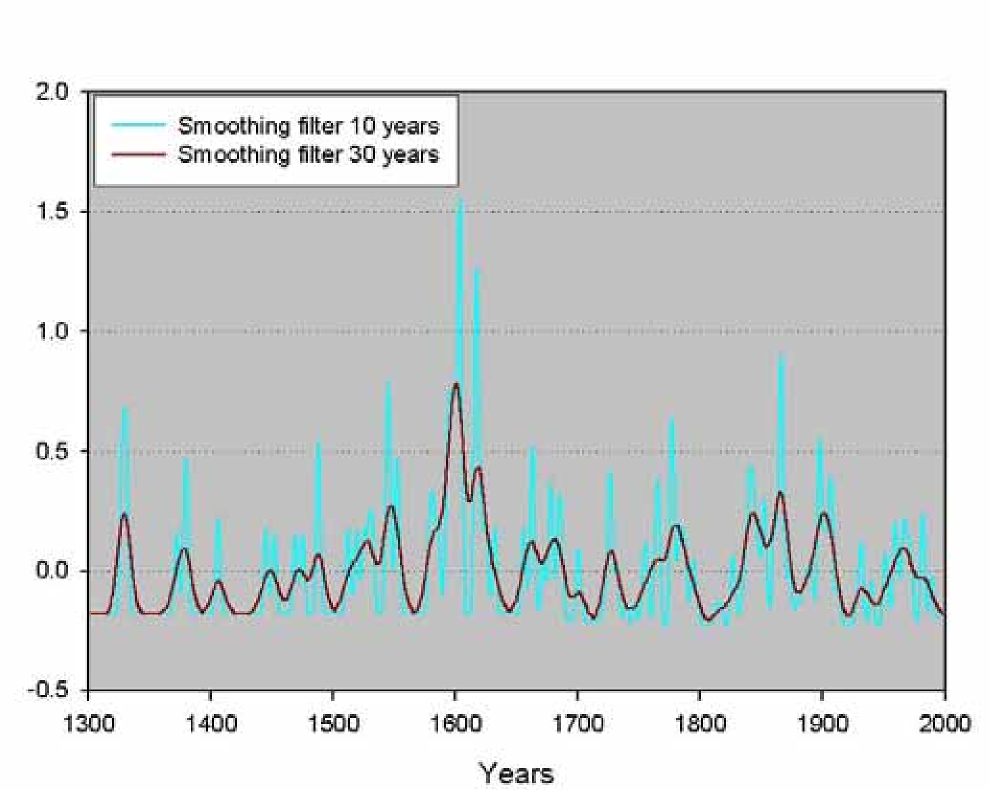

Fig. 12.A.6. *Frequency of extraordinary and catastrophic floods at Catalonia rivers (NE Spain). Values obtained from the application of a smoothed Gaussian weighted filter to times series (10 and 30 years) to the standardised mean (data from M. Barriendos).*

One aspect worth mentioning with regard to the LIA is the identification of extreme hydrological events that have not been recorded during the modern instrumental period (Fig. 12.A.7), but that can be repeated in future, under future climate scenarios and likely to cause unforeseen impacts. This appears to be the case of continuous torrential rains, causing catastrophic flooding in January-February of 1626 1708 1739 1856 1860 1876 1881 1895 and 1897 in the Atlantic basins (Guadalquivir, Guadiana, Tagus, Duero; Benito *et al.* 1996; 2003b) or the event of November 1617 in Mediterranean basins (Barriendos 1995; Fig. 12.A.6). Also identified are exceptional episodes of other phenomena that are more difficult to appreciate with regard to duration and magnitude, such as the continental cold spell from December 1788 to January 1789 (Barriendos *et al*. 2000).

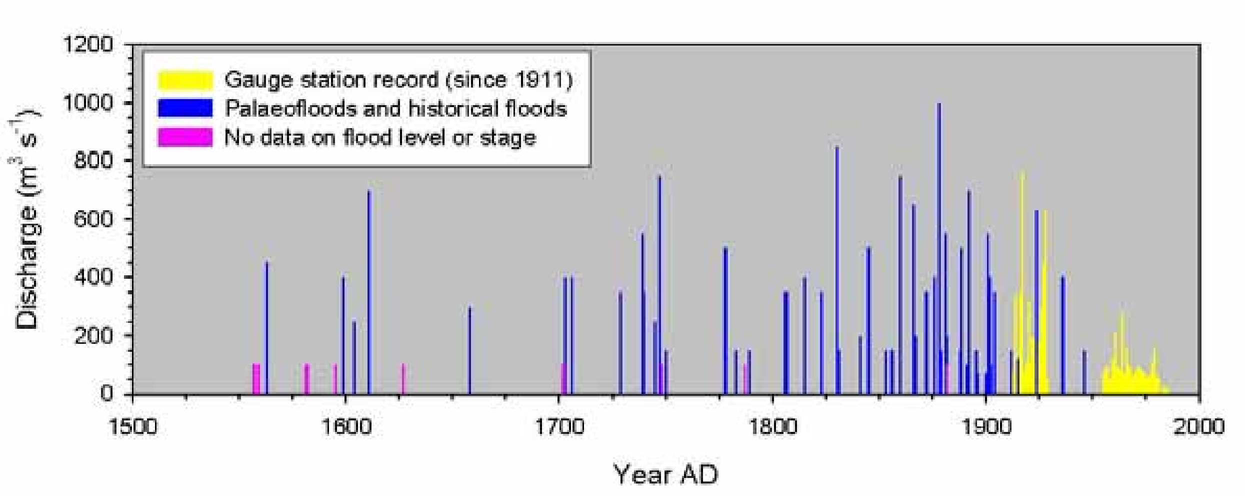

Fig. 12.A.7. *Peak discharges estimated for palaeofloods and documentary floods of the River Tagus at Aranjuez (after Benito et al. 2003), and data recorded at the gauging station (since 1911 in yellow).*

12.A.3. MAIN IMPACTS OF CLIMATE CHANGE

Even minor changes in climate can affect the number of hydrological extremes recorded in a year, their interannual frequency, as well as the duration, volume and peaks of recorded floods. Atmospheric patterns generating floods are complex and it is difficult to establish a direct and clear relationship between climate and floods.

Different indices have been established to define the position of zonal circulation in Europe in general and in Western Europe in particular. Among these indices the North Atlantic Oscillation index (NAO) is one of the most used and is defined as the standardised difference in pressure at sea level between two regional pressure centres: (1) a low pressure centre in Iceland and (2) a high pressure centre in the Azores (Walker and Bliss 1932; van Loon and Rogers 1978). Associations have been observed between these pressure differences and the distribution of winter rainfall and discharge in the Atlantic basins of the Iberian Peninsula (Trigo *et al*. 2003), particularly in the river Guadalquivir (Fig. 12.A.8). Periods with the NAO in a negative phase are associated with humid/wet conditions in the western Mediterranean and northern Africa (Wanner *et al*. 1994) and cold air in northern Europe. A study of the wintertime correlation between the NAO index and total winter precipitation in the different regions of Spain for the period October 1897 to September 1998 shows (Table 12.A.1) that the most sensitive areas to NAO are the basins on the Centre-North (Duero-Tagus) and Centre-South (Guadiana-Guadalquivir) of the Iberian Peninsula. Recent studies have shown that the NAO index decreases during secular maximums of solar activity and increases during periods of decreased solar activity (Kirov and Georgieva 2002).

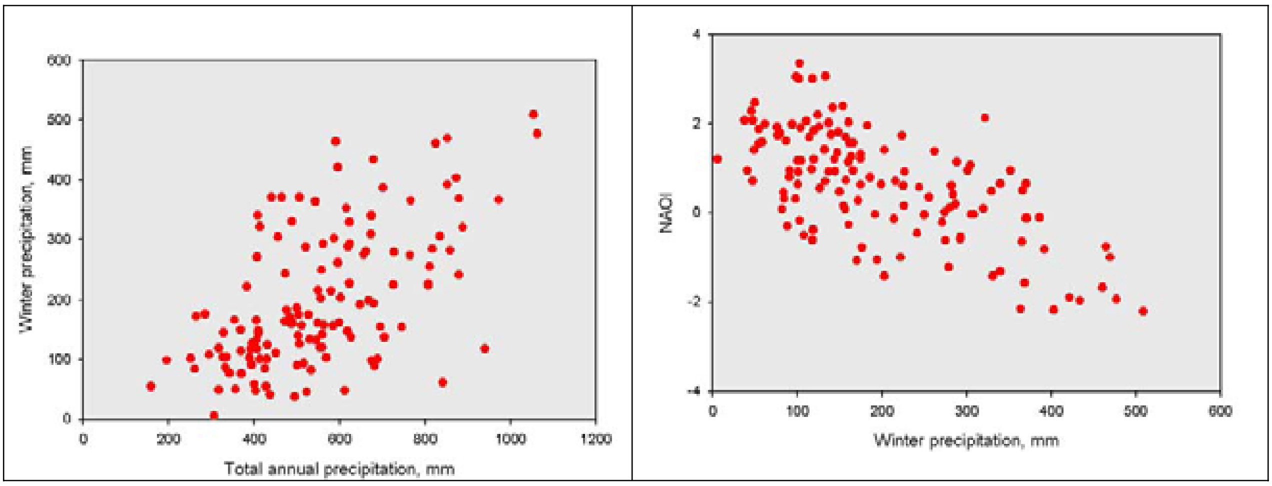

Fig. 12.A.8. *Left: Relationships between total annual rainfall and rainfall during the months of December-February (winter) in Seville (Gaudalquivir basin). Right: Winter precipitation versus North Atlantic Oscillation Index (NAO).*

Table 12.A.1. *Pearson's correlation coefficients between the NAO index (from December to March) and winter total precipitation in different pluviometric regions (after Barrera 2004)*

Region	NAO index (DJFM)
Northwest	-0,43
North	-0,51
Northeast	-0,59
Centre-North	-0,62
Centre-South	-0,72
Levante/East coast	-0,45
Canary Isles	-0,42

Given the complexity involved in the modelling of hydrological extremes through the use of atmospheric general circulation models, the response of floods and droughts can be estimated in scenarios of global change through the establishment of relationships between the NAO, solar activity and the magnitude and frequency of floods. Figure 12.A.9 shows the temporal variation in the NAO index, reconstructed by Luterbacher *et al*. (2002), and floods with discharges of over 3,500 m^3s^{-1} for the historic series of the Guadalquivir in Seville. A strong correlation is generally observed between periods with a higher number of extreme floods and periods of a negative NAO, as expected, given the correlation between rainy years and years with large floods in the Guadalquivir basin. However, negative NAO index values are not always related to the existence of extraordinary floods. The link between the NAO index and extreme floods, can also be detected in certain episodes, obtained through historic documents for the basins of the Tagus (Benito *et al*. 2003b and 2004) and Guadiana (Ortega and Garzón 2004), as well as a correlation between some flood periods and moments of maximum solar activity (Vaquero 2004).

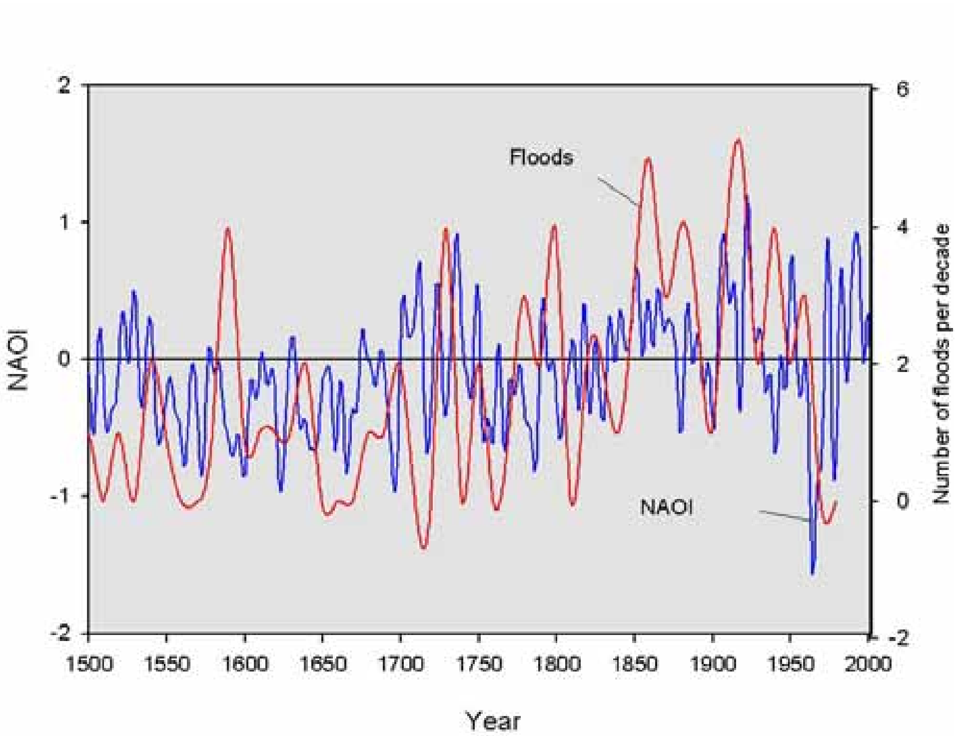

Fig. 12.A.9. *Number of floods with peak discharges over 3,500 m^3s^{-1} and variation in the mean of the NAO index for winter months (Dec-Jan-Feb) since AD 1500, with a smoothing filter for 3-year intervals. NAO index values after Luterbacher et al. (2002).*

Scenarios and predictions of future variations in this index are currently being generated with the use of climate simulation models (GCMs), which can be used to establish the patterns of future flood behaviour in Atlantic rivers. The projection of this index in relation to climate change resulting from the greenhouse effect is unclear and it is not agreed whether the tendency during the positive NAO phase in the 1980s and 1990s, when compared with the one from the 1900-1930 period, will be maintained or will intensify during the first half of the 21st Century. Presently half of the models predict a positive intensification of the index associated with global change, whereas the other half predict that the NAO index will remain at levels comparable to those of the last few decades. In both cases, if the NAO index increases or if it remains at the levels of past decades, we can expect a clear downward tendency of extraordinary floods in the Atlantic basins of the Iberian Peninsula in relation to the frequency patterns existing during the second half of the last century. This projection appears to tally with the GCM, which predict a 10% decrease in rainfall, which could lead to a decrease in the frequency of extreme floods in the basins of the large Atlantic rivers (Table 12.A.2). In the rivers Duero and Ebro, peak discharges could be affected by phenomena of rapid snowmelt as a consequence of sharp temperature rises during winter months and at the start of spring (Table 12.A.2). On the other hand, taking into account the last 400 years (Fig. 12.A.9), a high variability of the NAO is observed, even during episodes of global warming (e.g. the decades following the LIA). This NAO variability may produce an increase in hydrological variability within a scenario of climate change.

Regarding the Mediterranean basins, where the mechanisms established between climate and floods are more complex, no valid indices have been established or models developed to enable predictions to be made within a scenario of climate change. It is assumed that an increase in summer temperatures will likely favour the generation of storms (Table 12.A.2). These local storms may cause flash floods in small basins. In these cases, the temperature differences between the Mediterranean and the continent will favour convective rainfall over mountainous areas, especially in autumn.

In the Mediterranean rivers, palaeoflood and historical flood series indicate that extreme floods have occurred during episodes of irregular rainfall, both at seasonal and annual scales (droughts followed by flooding events; e.g. 2700 years B.P., and the start of the LIA). In recent times, an increase has been observed in the generation of intense rainfall, as occurred in the 1980s in the Mediterranean area of the Iberian Peninsula, which was interpreted as a response to climate change. However, this tendency was reversed in the 1990s, which reveals the complexity involved in the generation of extreme events.

Table 12.A.2. *Qualitative analysis of the response by different basins in Spain to possible impacts of climate change.*

Possible impact of climate change	Guadalquivir Guadiana Tagus	Duero	North	Ebro	Internal basins of Catalonia	Levante/South
Change in zonal circulation (positive NAO)	-Extremes (higher discharges) +Ordinary	-Extremes +Ordinary				
Increased cold pools			+Irregularity of extremes		+ Irregularity of extremes	+ Irregularity of extremes floods/droughts
Generation of convective rainfall	+Flash floods	+Flash floods	+Flash floods	+Flash floods	+Flash floods	+Flash floods
Sharp temperature changes		+Floods caused by the snowmelt		+Floods caused by the snowmelt	+Floods caused by the snowmelt	

12.A.4. MOST VULNERABLE AREAS

Apart from the likely increase in extreme events resulting from climate change, the areas more vulnerable to hydrological risks are those where there is also greater sensitivity or exposure of property. In this sense, vulnerability to floods in Spain should not be seen exclusively in terms of natural hazards related to a change on climate, but also in terms of the uncontrolled housing development of the last few decades. *A priori,* the type of area that is highly sensitive to hydrological extremes involves highly populated areas with recent housing development and with sensitive socio-economic sectors such as tourism and industry. Climate models predictions indicate an intensification of dry periods in summer and whereas the winter total precipitation should remain similar to the present, although concentrated in a shorter number of months. Studies conducted during the last decades indicate that the events with the biggest socio-economic impact are flash floods, which affect medium or small-sized basins. The areas with the highest statistically probability of being affected by flash floods, are located in the Mediterranean coastal belt, inland areas of the Ebro valley and other small catchments in the Iberian Peninsula present these characteristics. Moreover, in the case of the highest climatological and hydrological sensitive area of the Mediterranean coastal belt, with a high population density and high economical dynamics, the vulnerability is higher. (Fig. 12.A.10). In certain cases, with a moderate or low threat of extreme events, there can be a high degree of vulnerability due to greater exposure related to a lower social awareness of the problem. Likewise, torrential areas with frequent extreme events could present a lower degree of vulnerability if the necessary measures have been taken to lessen the risk. In general terms it can be said that, although the number and magnitude of hydrological extremes have decreased in recent decades, when compared to the first half of 20th Century, the estimated global damages were substantially greater (see see Chapter 15) due to the increased vulnerability and exposure of human activities along to the fluvial systems, as a consequence of the spread of urban areas.

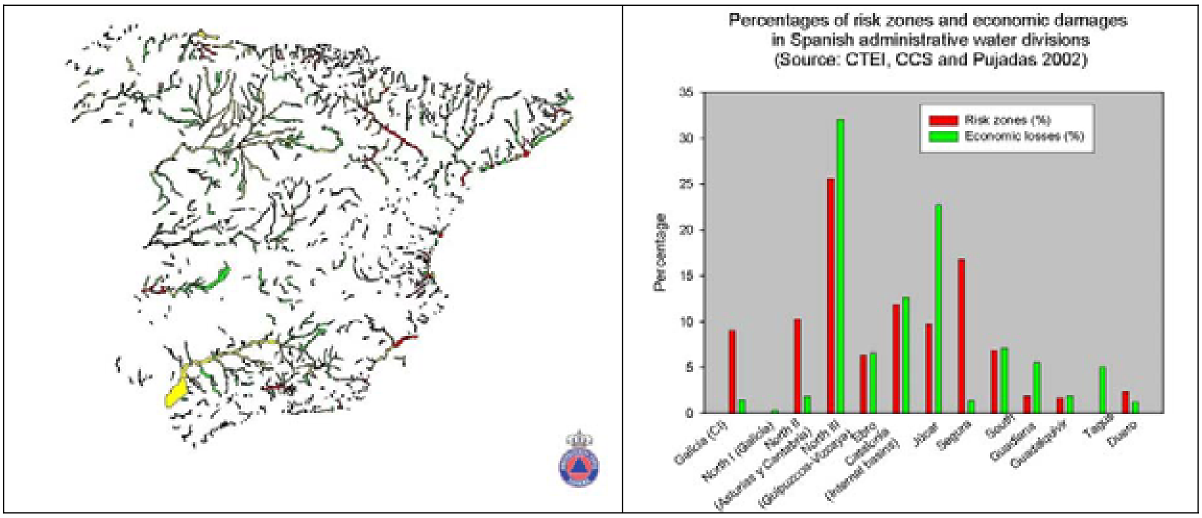

Fig. 12.A.10. *A: Map of conflictive areas due to flooding in Spain (source: Civil Protection). Legend: Red: High risk; Gre*In: *intermediate risk; Yellow: Low risk. B: Percentage of risk areas and economic losses in different basins (Pujadas 2002). In some basins a high percentage of losses is observed in comparison to the proportion of risk areas, which reflect their high vulnerability to floods.*

12.A.5. MAIN ADAPTATIONAL OPTIONS

The climatic, hydrological, physiographic and socio-economic variability of Spain prevent a generalised application of adaptational options throughout all the regions of the country. The best adaptational option lies in advances in the systems and methodologies of prevention and prediction (warning systems for medium and large-sized basins), and in the planning and management of risk situations. These best practices can be applied at three levels:

At the *technical level*, improvements are needed in the systems of protection of exposed property, based on structural and non-structural measures. Structural measures are generally applied to protect areas with a certain level of human activity, such as housing development, from the effects of floods. Non-structural and preventative measures should be promoted and based on regulations aimed at controlling construction in flood prone areas once the necessary protection measures have been developed. It should be pointed out that structural interventions to water courses (dams, weirs, channels and warning systems in real time) can never guarantee absolute protection.

At the *political and management level*, there should be more legislative control in the improvement of risk planning within town and industrial plans. In this respect, current legislation and sectorial regulation dealing with the hydrologic context and the Spanish Land and Valuation Law (*Ley del Suelo y Valoraciones*) are very ambiguous and ineffective. These laws should contemplate the compulsory application of the directives indicated by risk maps within the different scopes of town and land-use planning. The Water Law should clarify the definition of the river channel and flooded zone according to criteria based on geomorphological, hydrological, historical and ecological elements. The characteristics of the natural drainage network should be maintained, especially with regard to drainage capacity and sediment delivery, thus avoiding interventions that can block flows and promoting the environmental recovery of river areas.

At an *educational level*, there is a need to inform the population of the risk of natural disasters, encouraging prevention and reduced exposure. Subjects related to risk and prevention should be taught at school and information should be given on how to act in the event of a catastrophe. In this respect, previously flooded areas and the associated socio-economic consequences should be considered in the design of any policy or strategy aimed at dealing with floods.

12.A.6. REPERCUSSIONS FOR OTHER SOCIOECONOMIC SECTORS OR AREAS

Insurance sector. In Spain, the insurance cover for catastrophes, in particular for flood damage, is based on the application of a non-differentiated premium for all risks covered and for the whole country, this being handled by the Consortium of Insurance Compensation (CCS). Consequently, increased flood damage would not affect the private insurance sector to any great degree, because all insured parties pay a fixed amount, regardless of their degree of exposure to the risk (Table 12.A.3). In the case of drought damages, the private insurance and reinsurance companies could be affected economically due, fundamentally, to agricultural insurance.

Energy sector. This sector would be affected mainly in situations of prolonged drought, especially in the context of electricity generation (Table 12.A.3). Floods, when they occur, can negatively affect the transport and distribution of energy, whereas they can have a positive effect on the generation of hydroelectric energy, because floods can seasonally increase water resources.

Tourism sector. Flooding and news thereof in national and international media negatively affects the tourism sector (Table 12.A.3). For instance, tourism in the Tena valley (central Pyrenees) after the flood in the Arás stream, in which 87 people were killed, showed a decrease in the years following the catastrophe. Drought conditions have less impact on tourism, which may occasionally, though, be favoured by prolonged hot periods.

Industry and Transport sector. The transport and distribution sector is very sensitive to increases in floods, as these can cause the temporary closure of communication routes (Table 12.A.3). Periods of drought favour the transport and distribution sector but can negatively affect companies that require large amounts of water in their production processes.

Table 12.A.3. *Degree of positive (+) and negative (-) impact in different socio-economic sectors. 0: No impact; 1: low; 2: medium; 3: high*

Sector affected	**Floods**		**Droughts**	
	Increase	Decrease	Increase	Decrease
Insurance	-1	+1	-3	+2
Energy (hydroelectric and biomass)	+2	0	-3	+2
Tourism	-2	+3	-1	0
Industry	-3	0	-1	0
Transport and distribution	-3	+2	+3	+2

12.A.7. MAIN UNCERTAINTIES AND GAPS IN KNOWLEDGE

In Spain, advances are being made in the characterisation of scenarios of average rainfall and/or temperature extremes, which could be valid for the basins in which floods are related to the frequency of zonal circulation in winter months, as is the case of the Atlantic basins. In the case of the Mediterranean basins, however, there is a high degree of uncertainty, due to the fact that it is difficult to model the complex interactions in the Mediterranean environment related to extreme events.

These models require long time series of extreme phenomena in order to explain the response of floods to climate variability. Palaeofloods and documentary data can provide evidence of extreme hydrological events in Spain in relation to climatic variability in the last few millennia. Likewise, the study of rainfall series for the pre-industrial period (prior to the 20th Century) allows the natural component of climatic variability to be separated from the greenhouse effect, since the start of intensive CO_2 emissions.

12.A.8. DETECTING THE CHANGE

Around the world different authors have emphasized the high level of sensitivity of floods to slight climate variations. The detection of minor climate change can be observed in large modifications in the magnitude and frequency of extreme events. If we analyse available time series of floods over the last 2,500 years, the frequency and magnitude of floods occurred mainly at times of climate transition. Noteworthy among these, due to the increase and severity of the flooding, are the periods 1580-1620 and 1840-1870 in the Mediterranean (Barriendos and Martín Vide 1998) and in 1590-1610 1730-1760 1780-1810 1870-1900, in Atlantic basins. In the 20th Century, two periods were observed with increased magnitude and frequency of floods in Atlantic basins, namely 1930-1950 and 1960-1980, with a decrease in the peak discharges of extraordinary floods in the last 25 years. In the Mediterranean, great irregularity was observed in the patterns, with increased cold pools in the 1980s, which generated historic maximum discharges in 1982 and 1987, and a reduction thereof in the 1990s. From 1990 to 2000, there has been an increase in convective rainfall, which causes flash floods in small basins, such as those in Yebra and Almoguera (Guadalajara), Biescas (Huesca), Alicante, and Badajoz, and which had dramatic social consequences (207 fatalities). This change in the pattern of flood magnitude and frequency in Atlantic and Mediterranean basins may be interpreted as a sign of changes in the present climate.

12.A.9. POLICY IMPLICATIONS

Regardless of the severity of future climate change, hydrological extremes (floods and droughts) constitute the most obvious manifestation of climate and hydrology in Spain. Legislation must therefore deal with regard to dealing with land-use planning problems, including taking climate change into account in relation to hydrological risks. However, certain modifications are needed in the legal aspects of natural hazards. The political implications of climate change in natural hazards should involve improved management and legislation in risk-related aspects (Basic Directive of Civil Protection Planning), improved legislation in laws related to land planning (Water Law and Land Law), improvement and application of Watershed Management Plans, and the development of Technical Regulations for Dam and Reservoir Safety. Technical studies developed for the application of legislation should, wherever necessary, analyse the effects of climate change on floods and establish response strategies contemplating new scenarios of extreme events in relation to resources and land management.

In relation to floods, regulations should be revised in order to determine potential flooding zones and risk analysis within the land planning process, taking the floods that have occurred in the past into account. At present, the Land Law (Legislative Royal Decree1/1992) and the Water Law (Law 29/1985, dated August 2nd) and the Regulations on the Hydraulic Public Domain (Royal Decree 849/1986), dated April 11th) are too ambiguous in relation to extraordinary floods.

In the legislative aspect, it should be pointed out that land planning and population protection are currently the responsibility of the Regional Autonomies and therefore, they should take the initiative. So far, the Regional Autonomies have hardly developed any legislation in relation to flood risk, with the exceptions of the Basque Country, Catalonia and Valencia regions. These autonomies have developed their own emergency flood plans, which should subsequently be approved by the Civil Protection Department. In addition, these regions have introduced legislation on land-use planning in flooding zones and drawn up risk maps for their whole territory.

Within the European scope, The European Framework Directive on Water Policy (DIRECTIVE 2000/60/CE, dated October 23rd 2000) attempts to establish a framework for the protection of continental surface waters, transitional waters, coastal waters and groundwater. Recently, various documents on best current practices related to flood risks have been published, which in no case are binding in national regulations. This document makes specific mention of the increased flood risk resulting from climate change and constitutes the first steps towards the development of legislative measures aimed at legally binding Member States. Likewise, financial instruments have been established within the European framework, such as the so-called European Union Solidarity Fund (EUSF) aimed at mitigating economic damages deriving from natural disasters, and which are the result of the devastating floods that took place in August 2002 in Central Europe. These funds are based on the idea of dealing with the foreseeable repetition of catastrophes related to the negative environmental effects of human activities, and in particular, to reduce the impacts of climate change.

12.A.10. MAIN RESEARCH NEEDS

This report highlights the scant knowledge currently available on the effects of climate change on the magnitude and frequency of floods. In this respect, the main research themes to be developed in the future are the following:

- Reconstruction of flood series from the past based on geologic (palaeofloods) and documentary indicators.
- Analysis of the response of floods to climatic variability in the past in different regions of Spain.
- Improved reconstruction of the atmospheric situations associated with extreme events for long time series.
- Development of regional and local atmospheric circulation models for obtaining reliable scenarios of hydrological extremes, taking into consideration the distinct characteristics of the Atlantic and Mediterranean basins.
- Development of coupled climate-hydrology models for simulating extreme events at the basin scale.
- Downscaling methods of AGCM to drainage basin scale.
- Incorporation results of these studies into the analysis of flood frequency for use in land planning and the design of high-risk structures. Introduction of non-stationary data into risk planning, taking into consideration different scenarios of climate change.

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12. IMPACTS ON NATURAL RISKS OF CLIMATIC ORIGIN

B. SLOPES INSTABILITY RISK

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ABSTRACT

Slope instability causes economic losses of hundreds of millions of Euros every year, which fundamentally affect communication infrastructures and, to a lesser degree, population settlements. Whereas the number of deaths caused by landslides has decreased in the last few decades, there has been an increase in those caused by snow avalanches due to the fact that more people frequent the mountains.

Landslides and avalanches are concentrated in the main mountain ranges, especially in the Pyrenees, and the Cantabrian and Betic ranges. However, the banks of the rivers draining the large Tertiary basins are also unstable. Relief, together with the lithological component, account for the geographic distribution of the slope failures, whereas the origin of snow avalanches is due to both the accumulation of snow in the supraforestal and the steep relief. In coastal areas, failures are concentrated on rocky cliffs exposed to marine erosion.

The main triggering mechanisms of landslides are rainfall, melted snow, earthquakes, volcanic eruptions, and undermining by both waves and river erosion. Landslides can also occur spontaneously, for no apparent reason. Climate-related landslides are the most frequent. The relationship between climate and slope instability, however, is a complex one, due to the great variety of failure mechanisms. High-intensity, short-lasting rainfall episodes (over 100 mm in the Cantabrian range and over 180 mm in the Pyrenees) generally cause shallow landslides, debris flow and rockfalls. Prolonged low or moderate-intensity rainfall lasting for several days or weeks reactivate landslides and mudslides. The behaviour of large landslides is very dependent on the geological-geomorphological context thereof, but their reactivation is frequently associated with abnormally rainy seasonal periods. It must be kept in mind, in any case, that anthropic modifications (logging, leaks, overloading) are a frequent cause of new, apparently spontaneous slope faiures.

Two more rainy periods with associated landsliding activity were detected in the last century, in 1905-1930 and 1958-1987, and a relatively calm period from the 30s to the 50s. This apparent cyclicity has also been observed in other European regions, although not simultaneously. With regard to snow avalanches, no change in tendency, frequency or typology has been observed in the last few decades.

Uncertainty related to the increased frequency of torrential rainfall and abnormally rainy episodes prevent from any conclusive statement. Increased torrentiality will cause a greater number of shallow landslides and debris flows, the effects of which could be exacerbated by changes in land use and reduced plant cover. We can consequently expect increased erosion of slopes which will be seen in the degradation of the quality of surface waters, due to increased turbidity and a higher clogging rate in reservoirs.

The decrease in snowfall does not necessarily imply lesser avalanches, because of the increase in melting snow avalanches, although their geographic area can be expected to diminish.

The best adaptational tool involves regional and urban planning that avoids the development in the most susceptible areas. Winter tourism, however, could be negatively affected by the decrease in snowfall.

There is a need for a complete inventory of landslides and better damage assessment, as this is much greater than available figures reflect. There is a need for more in-depth study of the relationships between rainfall events and the different types of landslides.

12.B.1. INTRODUCTION

Slope instability involves the failure and displacement of a mass of rocks or earth down a slope, caused by the action of gravity. It is also generically known as landslide. Unlike other natural hazards, landslides are scattered throughout the territory, especially in mountainous or unpopulated areas. For this reason, there are less economical losses and casualties than in river floods or earthquakes. In any case, in the last 1,000 years, they have caused the death of at least 280,000 people throughout the world (Ayala-Carcedo 1994). The prediction of losses in Spain for the 1986-2016 period was estimated for a hypothesis of medium risk, at over 4,500 million Euros (Ayala-Carcedo *et al*. 1987).

The failure of slopes clearly affects local economy. Villages like Alcoi (Alicante); Castellbisbal, El Papiol qand Sant Sadurní d'Anoia (Barcelona); Arcos de la Frontera and Medina Sidonia (Cadiz); Benamejí (Cordoba); Blanes, Castellfollit de la Roca and L'Estartit (Girona); Albuñuelas, Almuñécar, Izbor, Monachil, and Olivares (Granada); Rosiana (Gran Canaria); Brallans and Tamarite de Litera (Huesca); Abella de la Conca, Cabdella, El Pont de Bar, La Coma, La Guingueta, Puigcercós, Sort-Bressui (Lleida); Argueda, Azagra, Falces, Funes, Lodosa, Peralta, Valtierra, (Navarre), to give a few examples, have suffered varying degrees of damage. Certain movements have also compromised the construction of dams such as Zahara (Cadiz), Arenós (Castellón), Beninar (Granada), Lanuza (Huesca), Giribaile (Jaén), La Viñuela (Malaga), Las Picadas and el Atazar (Madrid), Urdalur (Navarre), Contreras and Cortes de Pallás (Valencia). This required a lot of countermeasures and detailed programmes for monitoring of the movements (Sánchez and Soriano 2001)

The biggest damage, however, has been due to anthropic causes. In particular, as a result of changes in land use (logging, alterations of drainage on slopes) and due to excavations and cutslopes. Thus, on roads, there are frequent both slope and embankment failures, which occasionally isolated valleys and the populations therein, like what occurred in La Massana (Principality of Andorra) in October 1987 which cut the valley off from the Valira del Nord for a month. Although no official figures are available, the costs of slope instability surpass by far hundreds of millions of Euros a year. The winter rains alone in 1995-96 and 1996-97 in Andalucia caused hundreds of cutslopes and embankment failures on the principal roads. In the province of Malaga, for example, at a section of only 10 km between Ardales and Campillo, there were over 100 failures (González *et al*. 1997). The costs and inconvenience caused in the huge traffic jam by the collapse of embankments in March and May 2004, on the A-3 motorway in Perales de Tajuña (Madrid) or on the AP-7 in Viladesens (Girona), respectively, are difficult to estimate.

The increasing use of mountainous areas for tourism and sports activities, has led to an unusual frequentation in clearly unstable areas. New roads and human settlements are spreading towards places in which slides, rockfalls and other type of movements occur relatively frequently, thus increasing the risk for people and facilities. This is why the number of isolated incidents increases year after year (table 12.B.1).

In slope instability, snow avalanches are having an increasing impact. The more frequent practice of winter sports in the last 15 years has led people to frequent the mountains more in Spain's different ranges. To the habitual practice of alpine skiing within the demarcated skiable domains, we must add off-track skiing, mountain and cross-country skiing and winter mountaineering. The intense development of ski resorts leads to the development of high-mountain valleys, changes in land uses and the need to keep roads open throughout the winter. As a consequence, high-mountain areas in Spain traditionally exposed to the risk of avalanches are currently frequented by a large number of skiers, mountaineers, buildings, roads and other infrastructures.

Table 12.B.1. *Landslides in the last 150 years with victims and relevant damages (own compilation based on different sources)*

Site	Date	Type	Consequences
Felanitx (Majorca)	31 March 1844	failure of embankment	414 dead and 200 injured
Azagra (Navarre)	1856	rockfall	11 dead
Azagra (Navarre)	21 July 1874	rockfall	92 dead and 72 houses destroyed
Puigcercós (Lleida)	13 January 1881	slide	Houses destroyed. Village abandoned
Albuñuelas (Granada)	25 December 1884	slide	102 dead and over 500 injured. 463 houses destroyed
Azagra (Navarre)	20 January 1903	rockfall	2 dead
Bono (Lleida)	26 October 1937	Debris avalanche	River dammed
Rocabruna (Girona)	18 October 1940	Debris flow	6 dead
Alcalá de Júcar (Albacete)	1946	rockfall	12 dead and several houses destroyed
Azagra (Navarre)	13 May 1946	rockfall	2 dead
Rosiana (Gran Canaria)	17 February 1956	slide	Bridge and houses destroyed. 250 evacuated
Benamejí (Cordoba)	February 1963	slide	55 houses destroyed and 50 damaged
Senet, Benasque (Huesca),	3 August 1963	debris flow	River dammed. Road affected
Villanueva de San Juan (Seville)	May 1964	Earthflow	Partial obstruction of river. Road closed
Alcoi (Alicante)	December 1964	Rotational slide	Cracking in houses
Pont de Bar (Lleida)	7 November 1982	Slide	Houses destroyed. Village abandoned
Capdella (Lleida)	7 November 1982	Debris flow	3 dead
Cabra del Camp (Tarragona)	September 1987	rockfall	1 dead. Bus hit
Guixers (Lleida)	October 1987	rockfall	2 dead. Vehicle hit
La Massana (Andorra)	October 1987	Slide	2 dead. Vehicle hit
Benamejí (Córdoba)	27 December 1989	Slide	Dozens of houses affected
Camprodón (Girona)	May 1992	Debris flow	2 dead
Collado Escobal (Asturias)	December 1993	Slide – debris flow	3 dead. House destroyed
Sant Corneli (Barcelona)	17 December 1997	Slide	1 seriously injured. Road closed
Ampuero (Cantabria)	10 January 1999	Slide – Earthflow	Several houses destroyed
Montserrat (Barcelona)	10 June 2000	Debris flow and rockfall	Different roads and cable car damaged
Tenerife	31 March 2002	rockfalls	TF-1, TF-2 and TF-5 roads closed
Mogán – Gran Canaria	12 December 2002	rockfall	1 dead –vehicle hit
Cala Sr. Ramon de Palafrugell - Girona	25 August 2003	rockfall	2 dead and 2 injured
Barruera – Vall de Boí-Lleida	20 September 2003	rockfall	2 injured. Road closed.
Buscabrero de Salas (Asturias)	16 November 2003	slide – debris flow	2 dead - house

From 1990 to 1999, 47 people lost their lives in Spain in snow avalanches. The Massifs or ranges with the highest death rates were the Pyrenees, with 41 victims, but there were also victims in Sierra Nevada (1) and in the Cantabrian Range (5). The number of casualties in avalanches has been rising: 25 in the seventies, 38 in the eighties and 47 deaths and 37 injured in the nineties (ICC database; López *et al.* 2000; Rodés 1999). The annual average of fatal victims caused by avalanches since 1970 is between 3 and 4 (an average of 3.5 deaths in the last 30 years). In the decade 1990 – 1999, the annual average increased to 4.7 deaths. This increase is accounted for by the high accident rate in the 1990 – 1991 season which, with 22 deaths, practically represents 50% of all deaths in the decade. One of the most serious accidents occurred in this season, with a very high number of deaths. A group of soldiers doing military ski exercises in El Pico de Paderna (Benasque valley) caused a slab avalanche which killed nine people.

In view of the activity in the mountains in the winter season, in 1990 in the Pyrenees of Catalonia a programme was initiated for the systematic collection of information on all avalanches involving people. The data obtained showed that the lives of a high number of people were endangered by the threat of avalanches, a total of 187 people in 38 accidents during the nineties. Unfortunately 20% of these correspond to deaths or serious injuries (6% deaths and 14% injuries).

12.B.2. SENSITIVITY TO CLIMATE

12.B.2.1. Sensitivity to the present climate

12.B.2.1.1. Triggering factors of slides and avalanches

A trigger is an external stimulus that causes the almost immediate failure by means of the rapid increase in stresses or the reduction of the resistance of the material the slope is composed of. The main mechanisms causing landslides are rain, melting snow, earthquakes, volcanic eruptions, undermining by waves and river erosion. Landslides can also occur spontaneously for no apparent reason.

Rainfall is the most frequent and widespread landslide trigger in Spain. It causes instability due to the infiltration of water into the slope, with the consequent increase of pore water pressures and joints of the terrain, thus reducing its strength. The ratio between the amount of water that has infiltrated and what drains out of the slope controls the changes in groundwater pressure. With rainwater infiltration, water pressure rises to the critical level at which the failure occurs. The rate of infiltration is controlled by the topography, plant cover and the permeability of the materials. Furthermore, slope stability is conditioned by the resistance of the terrain and by the geometry thereof. The critical rainfall needed to cause a failure will vary from one slope to another and establishing regional rainfall thresholds in relation to the failure of slopes therefore involves a noteworthy level of uncertainty. Nevertheless, the thresholds obtained are of inestimable usefulness in risk management.

It must be kept in mind that human action conditions to a great extent the occurrence slope instability events, giving rise to landslides that are apparently spontaneous. Thus, leaks in water supply or drainage systems, alteration in vegetation cover or land use changes (forest logging, new pastures, excavations, mining etc.) lead to modifications in the stress field on slopes. These actions often favour the slope failure under relatively moderate conditions with regard to the triggering factors.

Human influence is also evident in provoking snow avalanches. If we analyse the number of casualties according to types of avalanches, slab ones are those that present the highest risk level for mountaineers. A figure of 44% of the total number of victims corresponds to recent snow avalanches, 38% to slab avalanches, and melted or wet snow avalanches 18%. Recent snow avalanches generally involve large amounts of powder snow unleashed by natural factors which has a heavy impact upon victims. Slab avalanches, on the other hand, involving skiers and mountaineers are usually accidentally caused by the victims themselves, when they are on the slab. In accidents related to melted or wet snow avalanches (flows of dense snow caused by temperature rises) the casualties are usually hit by the flow on the slopes or in the hollows.

12.B.2.1.2. Meteorological conditions and slope stability

In spite of the possible multiple causes of slides, the vast majority of landslides are caused by the rainfall regime on the Iberian Peninsula. All the main movements in Catalonia in the XX century have been the result of rainfall episodes. In the Asturian Coal Basin, an analysis of 213 landslides from 1980 to 1995 (Domínguez 2003) showed that 80% of these were the direct result of rainfall, whereas the rest were due to anthropic causes (works, filtration, mining...). Two very intense rainfall events (over 100 mm in 24 h) have been recorded in Cantabria in 1983 and 1994, that caused numerous landslides throughout the whole region (González-Díez 1995). In a review of 20 landslides throughout Spain, Ferrer and Ayala (1997) observed that failures and reactivation in slides, earthflows and debris flow occurred during abnormally intense rainfall episodes, with values ranging from 15 to 120% of mean annual rainfall. Lamas *et al*. (1997) found that the rainfall that caused landsliding episodes in Andalucia from 1996 to 1997 exceeded the historic maxima of the last 100 years in 30% of the weather stations. The rainfall accumulated from November 1996 to January 1997 was over double the value corresponding to the same seasonal period in all the observatories in the Southeast of Andalucia.

The duration and intensity of rainfall episodes, the materials comprising the slope and the morphology thereof are the main factors conditioning the type of landslide. In the Pyrenees, three situations have been distinguished that cause slope failure or the reactivation of slides (Moya and Corominas 1997; Corominas *et al*. 2002): (a) short duration high-intensity rainfall cause widespread shallow slides, debris flow and rockfalls; (b) rainfall episodes of moderate to low intensity that last for several days or weeks reactivate rotational and translational slides, and mudslides; (c) abnormally rainy seasonal and interannual episodes cause the reactivation of large-scale slides. In particular geological contexts, short duration rainfall can also cause reactivation.

In the Cantabrian Range, a relationship has been established, for the last 100,000 years, between periods of increased rainfall and greater frequency of landslides (González-Díez *et al*. 1996 1999). At a scale of the last few decades, the relationship is well known between intense rainfall episodes (e.g., in August 1983) and slides, in particular shallow ones (Remondo 2001, Remondo *et al*. 2004; Cendrero 2003; Cendrero *et al*. 2004; Remondo *et al*. 2004).

Rockfalls are frequent during rainy periods. These are caused, however, by the effect of freeze-thaw cycles, root penetration or in a spontaneous manner, due to the action of weathering mechanisms. For this reason, the relationship with rainfall is a weak one. Both the steep slopes in valleys shaped by glacial processes, and all other rock cliffs present stress release joints, which are a source of rockfalls. The rate of occurrence of rockfalls appears to have been conditioned more by temperature fluctuations, around º0, than by rainfall regime during the Little Ice Age (Grove 1972).

Shallow slides and rockfalls

On slopes covered with surficial deposits (colluvium) and weathered rocks, intense rainfall of short duration are capable of triggering slides, debris flow and rockfalls. In the Eastern Pyrenees, analysis of the isoyets and their relationship with the distribution of landslides in different recent episodes has allowed the establishment of a rainfall intensity threshold of 180-190 mm in 24-36 h (Gallart and Clotet 1988; Corominas and Moya 1999). In these cases, antecedent rainfall was not necessary. To the contrary, persistent low-intensity or moderate rainfall hardly causes shallow slides at all. This is due to the presence of large interparticular voids in the colluvium and of macropores (root casts, piping, animal burrowing) in weathered claystone formations, which facilitates rapid drainage of infiltrated water from low-intensity and moderate rainfall. Only high-intensity rainfall can generate significant increases in pore water pressure leading to the failure. This threshold is not far off 171 mm in 19 hours, which in June 2000 caused numerous events of debris flow, slides and rockfalls in Montserrat (Marquès *et al*. 2001).

Determined local contexts can modify these relationships. In Cantabria the occurrence of shallow slides has been noted on steep slopes, sculpted in Keuper materials, with rainfall intensities of between 50 and 65 mm/h, well below what was to be expected. The current hypothesis is that during months with greater accumulated rainfall, a strong groundwater flow is generated through existing piping in Keuper clays, rich in gypsum. When rainfall intensity increases, water rapidly concentrates in the pipes and is capable of triggering “argayos” (shallow slides) at the groundwater outlet point.

In road and railway cutslopes, these thresholds can show a substantial downward trend. This is due to the fact that the stability of the cutslopes is also conditioned by geometry (angle and height of the cuslope) and to the excavation procedure which, depending on whether this was done mechanically or with explosives, can affect the quality of the rock. Thus, the rainfall instability threshold for slope and cutslope failures in Asturias has been established at 60 mm in 24 hours (Domínguez *et al*. 1999; Domínguez 2003) and in the Eastern Pyrenees at 110 mm in 24 hours (Moya and Corominas 1997; Moya 2002), well below what has been observed on natural slopes. This lower threshold may also be explained by the inability of the soil to store water in the cut-slopes.

Slides and earthflow

Earthflow and rotational and translational slides, with volumes from a few tens to hundreds of thousands of cubic metres, are usually reactivated during moderately intense episodes, between 40 and 100 mm of rainfall in 24 h, provided that 90 mm or more of rainfall has accumulated in the preceding days (Corominas and Moya 1999). This type of slides occurs in low-permeability clayey and silty-clayey geologic formations. In these formations, the infiltration of rainwater is controlled by the size of the particles and, to a lesser degree, through fissures and by recharge through the more permeable layers, such as interbedded sandstone. The authors quoted have established the following threshold for the Pyrenees:

$$I = 66.1\ D^{-0.59}$$

Where I, is average rainfall intensity in millimetres per day and D is the duration of the storm in days. The expression is valid for rainfall episodes of a duration of more than one week, and which have accumulated at least 90 mm of rain.

Large landslides

Historical records show that most first-time failures in large landslides were caused by non-climatic factors (Corominas 2000). To the contrary, rainfall is the most frequent cause of reactivation of dormant slides and of the acceleration of those that are already active. It is not easy to establish the relationship between rainfall and slide activity; this is due to the fact that we do not yet avail of sufficient knowledge of the hydrological behaviour of large slides. Advances in this field require complex mechanical-hydrological modelling, which needs a great deal of data on the terrain and instrumental ones, which are rarely available. In general, long rainy periods (at seasonal, annual or ten-year scale) appear to have a certain influence in the reactivation of large landslides (figure 12.B.1) although the relationship can often only be established in a qualitative manner.

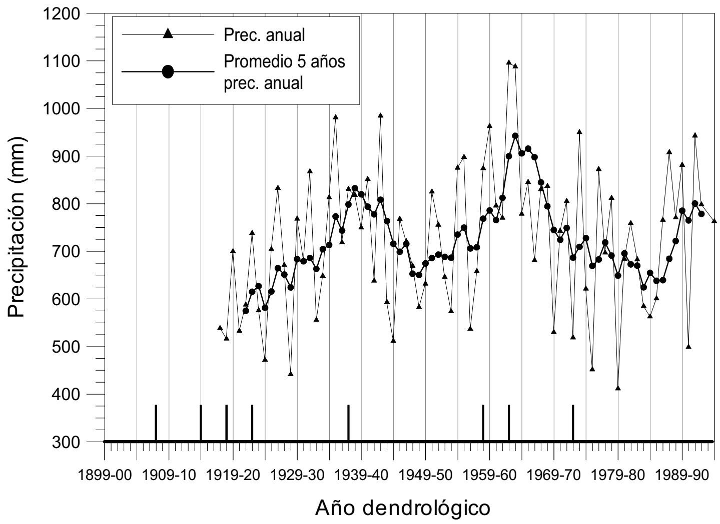

Fig. 12.B.1 *. Reactivation episodes (vertical bars) of the landslide of the Barranco de Boés in Llavorsí (Central Pyrenees) and the relationship between this and mean annual rainfall and that recorded over five years in the Capdella weather station. Reactivation episodes have been identified with the use dendrogeomorphological analysis. (Corominas et al. 2004).*

However, in very particular geomorphological contexts that favour instability, either through extraordinary amounts of groundwater (e.g. contact with karstic massifs) or due to brusque topographic changes (e.g. toe erosion), landslides can be reactivated by very intense, short-lived rainfall episodes. Some cases were observed during the intense rainfall on November 6^{th}-7^{th} 1982 in the Eastern Pyrenees (Corominas and Alonso 1990). Some slides are also in permanent movement, like in Vallcebre (Eastern Pyrenees), with a volume estimated at over $20x10^6$ m^3 (Corominas *et al*. 1999). The presence of cracks, which facilitate rainfall infiltration into the slide, together with toe erosion by a torrent can facilitate the acceleration of the movement in a question of a few hours (figure 12.B.2).

Omission of these aspects could give rise to an erroneous perception of the role of climate in causing slides.

12.B.2.1.3. Instability of slopes in Spain. Spatial distribution

The distribution of slides in Spain is governed by two fundamental elements: relief and the presence of susceptible materials (table 12.B.2). Vegetation and land use also have an effect, but to a lesser degree. Climate, erosion and earthquakes are, in that order, the most frequent triggering mechanisms. The western and central sectors of the Peninsula, which constitute the Hercinian basement of the Plateau, are the least problematic ones. This is due to the resistant characteristics of the materials (plutonic rocks, gneiss, quartzite and schist) and to the gentle morphology (Araña *et al*. 1992). To the contrary, mountain ranges present the highest number of phenomena, favoured by their relatively young relief, high rainfall and the presence of susceptible lithologies. The eminently carbonated nature of outer Ranges of the Plateau makes these areas relatively stable; the clayey and sandy formations, abundant in certain parts of the Cantabrian Range, are highly unstable. In Tertiary basins, it is common to find tabular reliefs resulting from the sub-horizontal arrangement of the strata. The rivers draining these basins excavate big valleys the sides of which are composed of highly unstable silty or clayey materials.

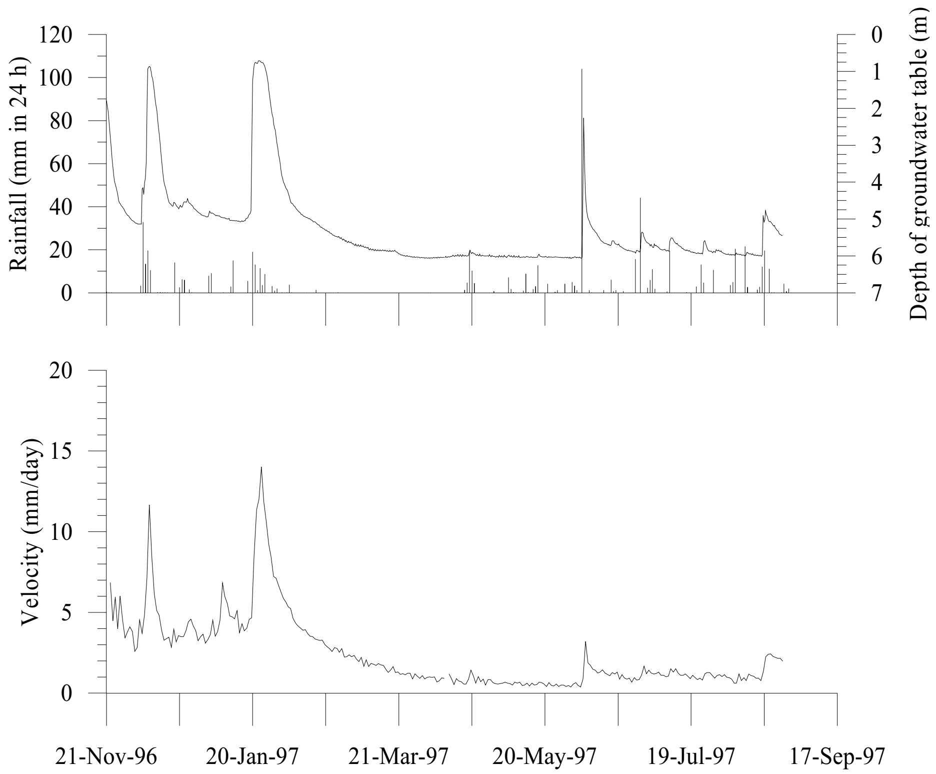

Fig. 12.B.2. *Rainfall episodes and slide response in Vallcebre (Barcelona). Above: rainfall record (vertical bars) and changes in groundwater levels in the borehole S-2. Below: rate of horizontal displacement of the ground surface at the borehole end (Corominas et al. 1999).*

Taking into account the morpholithological context, three main domains of slides can be distinguished: (a) the main mountain ranges, (b) Neogene depressions and (c) coasts with cliffs.

<u>(a) Slope failures in the main mountain ranges</u>. The Pyrenees, the Cantabrian Range, Iberian Range, the Baetic Ranges and the Coastal Ranges of Catalonia concentrate a great deal of these failures, due to the coincidence of a sharp relief, sculpted to a great extent by glacial and/or periglacial (active or relict) morphogenetic systems, the presence of susceptible terrain and a favourable rainfall regime, especially in the Mediterranean area. Two factors of relief that favour instability can be highlighted: the steepness of slopes due to the erosive action of the Pleistocene glaciers and the valley cutting by the present fluvial network, favoured in some cases by mechanisms of orogenic uplift (e.g. valley of the river Guadalfeo, Baetic Ranges). Materials susceptible to sliding are fundamental in slope failures. There are different sensitive lithostratigraphic formations that are often affected by phenomena of instability. A synthesis of the most susceptible lithologies of the Pyrenees can be found in Corominas and Alonso (1984). In this range, the Silurian shales have given rise to large landslides in Pardines and Nevà (Girona), Pont de Bar and Arduix (Lleida), mainly earthflow but also translational slides (Bru *et al*. 1984a; Fleta 1988). Likewise, the marls and gypsum of the Keuper cause rotational slides and eathflows in Pont de Suert. The Mesozoic flysch facies cause complex rotational failures and flows, or slides from the Nogueras area to the Jaca basin. In glacial deposits (tills), there are abundant debris flow and avalanches, as well as rotational slides (Brocal 1984; Bru *et al* 1984b). The instability of these materials have left deep scars in La Guingueta, Artíes, Taüll, Capdella and Bono (Lleida), Senet and Benasque (Huesca). Colluvia cover a wide area of the slopes and give rise to slides and debris flow. Of particular significance were the events in

October 1937 in the upper Segre basin, October 1940 in the Ter basin, November 1982 in the basins of the rivers Llobregat, Segre and Nogueras.

Tabla 12.B.2. *Unstable lithologies in Spain. associated types of failure and geographical distribution (synthesis based on data from Corominas 1985; Corominas 1989; Araña et al. 1992; Corominas 1993).*

Lithology	Age	Type of failure	Area
Black shales	Silurian	Slides, earthflows	Pyrenees
Claystones and gypsum	Keuper	Rotational and translational slides, earthflows	Pyrenees, Coastal Ranges of Catalonia, Cantabrian Range, Iberian Range, Tramuntana Range, Subbaetic System
Red-lilaceous clays, marls and siltstones (Weald Facies)	Lower Cretaceous	Rotational and traslational slides	Cantabrian and Iberian Ranges
Alternancias of blue marls with limestones	Aptian	Rotational and translational slides and earthflow	Iberian Range
Alternances of lutites, red sandstones, lignites (Facies Garum)	Upper Cretaceous	Rotational and translational slides and earthflow	Pyrenees
Marly clays	Lower Eocene – Lutecian	Rotational slides and earthflow	Pre-Pyrenees, Prebaetic Ranges
Marls and alternances of sandstones, marls and limestones (Flysch)	Eocene inferior	Earthflow, slides	Pyrenees, coast of Cantabria
Massive gypsum	Oligocene	Rockfalls and topples	Ebro Basin
Clays, sandy silt	Miocene	Rotational slides and mudslides	Duero, Tajo Basins. Mountain depressions in Vallès-Penedès, Cerdanya, Granada, Hoya de Alcoy
Boulders and gravels with sandy-silty or clayey matrix (glacial till)	Pleistocene	Debris flows and avalanches. Rotational slides	Pyrenees, Cantabrian Range,
Gravels, sand, silt and clays (coluvium)	Pleistocene-Holocene	Slides and debris flow	All the mountain ranges
Basalts	Miocene, Pliocene, Pleistocene	Large slides Rockfalls	Canary Isles, Olot Region

In the Cantabrian Range there is a great abundance of sediment formations with clays with interbedded marls and siltstones from the Weald Facies and the Keuper Facies. These formations produce rotational and translational slides, like in the Pas valley (Fernández-Montero and García Yagüe 1984) and in the Miera, Saja Besaya valleys (García-Yagüe and García-Álvarez 1988; González-Diez *et al*. 1996). The lignite layers present in the Carboniferous formations in the Sil valley also favour large translational slides. Like in the Pyrenees, colluvium cover constitutes the source of shallow slides and debris flow; this became clear in August 1983 in the Basque Country and Cantabria. In the Baetic Ranges, the unstable materials are relatively young. The clays and marls from the Lower-Mid Cretaceous cause mudslides like the in Olivares (Rodríguez-Ortiz and Durán 1988; Chacón and López 1988). In the Baetic domain there are abundant translational and rotational slides and debris flow, especially in phyllites (El Hamdouni 2001; Chacón *et al*. 2003) whereas in the Subbaetic, the predominance of outcrops of Jurassic and Cretaceous marls can be seen in the abundance earthflows (Irigaray and Chacón 1991; Irigaray 1995). In the Iberian range, interbedded marls among the calcareous formations have allowed for the development of large slides and earthflows, like in Puebla de Arenoso (Castellón).

Apart from the presence of a susceptible lithological formation, the structural arrangement thereof also conditions the appearance of slope failures. Even in resistant rocky formations, phenomena of instability occur with certain frequency, these making use of structural weaknesses (bedding planes, joints, faults, schistosity planes). When the latter dip unfavourably in relation to the orientation of the slope, large slides can occur, both in calcareous formations and in granites or sandstone. This is particularly evident in the sedimentary formations in the pre-Pyrenees, Cantabrian Range and Baetic Ranges. This accounts for the large translational slides like the ones in Vallcebre (Corominas *et al*. 1999), those in the Magdalena-Pas valley and Miera in Cantabria (González-Diez 1995; González-Diez *et al*. 1999), those in the Asturian Coal Basin (Menéndez 1994; Domínguez 2003). In the Beatic Ranges, translational slides are associated with metapelites and rotational ones with phyllites and schists (Chacón and Soria 1992; Fernández *et al*. 1997a).

Thus, the steep relief along with the harsh climatic conditions (ice) facilitate the development and opening of cracks which, in turn, facilitate the appearance of rockfalls and topples in these rocky formations. In limestone and Cantabrian quartzite reliefs, the unfavourable orientation of the strata and joint sets has favoured the development of rock avalanches (Jiménez 1997; Menéndez and Marquínez 2002).

Snow avalanches occur in the main mountain ranges. If we treat the number of victims according to mountain ranges, it can be seen that 61% of these have occurred in the Aragón Pyrenees and in Navarre, and 26% in the Pyreness of Catalonia. The accident rate has been doubled in the Pyreness of Catalonia than in Aragón, but in the latter region the accidents have been more serious and have caused more victims. The number of deaths in the Cantabrian Range was 5 (4 in Asturias and 1 in Palencia) and in Sierra Nevada (Granada) there was one death for the same period considered.

(b) <u>Neogene basins</u>. The Duero, Tajo and Guadalquivir valleys, and the intramontaneous basins such as those in Cerdanya, Vallès-Penedès , el Bierzo, Hoya de Alcoy or the Granada basin, are filled with thick detritic formations among which can be found big layers of continental and marine clays and gypsum formations interbedded with marls. The migration of the meanders of the main courses, which causes the erosion of slope foot, is the main cause of translational and rotational slides on the banks of the Duero (Berganza and Modrano 1978; Martínez and García Yagüe 1988; Monterrubio *et al*. 2001), of rockfalls and topples on the banks of the Ebro (Gutiérrez *et al*. 1994) and of the Guadalquivir. The valley cutting by the tributary network destabilises the slopes in the lower basin of the river Llobregat (Bordonau and Vilaplana 1987), in the basin of the river Anoia (Barcelona), in the the Bierzo Depression (Alonso and Lloret 1988) and in the Granada basin (Chacón *et al*. 2001 and 2003). Although these landslides are not usually very large some of them can reach several million cubic metres, like the one in Benamejí (Cordoba) or Hontoria and Tariego de Cerrato (Valladolid).

(c) <u>Coastal Cliffs and Volcanic Islands</u>. The whole Cantabrian coast from the Basque Country to Asturias presents numerous slide phenomena resulting from erosion and undermining of the cliffs. In particular, the outcrops of Eocene flysch in the Basque Country (Salazar and Ortega 1990) and the Bay of Cadiz (Andreu and Martínez-Alegria 1984), the facies Keuper in Asturias (González-Villarías 2001) and the northern coast of Majorca (Ferrer *et al*. 1997; Mateos 2001). The granite and fractured limestone massifs on the Costa Brava produce frequent falls of blocks and rock wedges. In the Canary Isles, erosion and retreat of the stacked lava flows generates imposing cliffs with frequent rockfalls.

The Canary Isles constitute a very particular context. The piling of successive lava flows and pyroclastic materials has built volcanic structures that have produced the largest landslides known in Spain, of around several cubic kilometres, like in the Oratava valley and in Teguise on Tenerife (Bravo 1962; Ancochea *et al*. 1990; Watts and Masson 1995) the one of Golfo on Hierro (Soler 1997), la Palma (Carracedo *et al* 1999) etc. These landslides are prehistoric, and although the most accepted hypotheses for failure indicate an origin associated with the accumulation of volcanic material, dyke intrusions and the associated seismicity, and marine erosion, we cannot rule out the influence of climate as an additional factor (Hürlimann *et al*. 1999) and, indirectly, the drop in sea level associated with glacial episodes (Carracedo *et al* 1999; Ablay and Hürlimann 2000). In Gran Canaria, the surface of failure of the large slides in the Tirajana Depression have made use of the presence of weak layers (tuff, ashes and ash flows) interbedded in the lava flows (Lomoschitz *et al*. 2002).

12.B.2.1.4. Seasonal distribution of the landslides

There is notable heterogeneity in the temporal distribution of slope failures between the Mediterranean environment and the rest of the Peninsula. In the last century, the biggest episodes of slope instability in the Coastal Mountain Ranges of Catalonia, the Eastern Pyrenees and the Iberian Range, were fundamentally concentrated in Autumn –October and November – although there have been sporadic episodes distributed throughout the other seasons. In the Cantabrian Range, in the Betic Ranges and in the Neogene Basins, there is a predominance of failures in winter. An analysis of the instability events in the Asturian Coal Basin over a 15-year period (1980-1995) shows that most of the 213 failures occurred in November, December and April (Domínguez 2003). Rainfall episodes, however, are not unusual in spring-summer, and these cause numerous slides. For instance, the aforementioned one in August 1983 was probably the one that caused most slides in the last few decades in Cantabria and the Basque Country (Remondo *et al*. 2004). On the Canary Isles, slides and rockfalls are mostly concentrated in the winter months.

12.B.2.1.5. Changes in slope failure frequency and recent reactivation

The last few decades of the last century were particularly active with regard to the occurrence of new breakages and reactivation episodes. In the central and eastern Pyrenees, the reactivation of medium and large-sized slides and earthflows (figure 12.B.3) has increased. Observing the reactivation records obtained with the use of dendrogeomorphological techniques, covering the whole of last century, one can see a certain cyclicity with the presence of two wet periods of greater activity: 1905-1930 and 1958-1987. There was a relatively quite period from the 30s to the 50s, and in the last third of the last century, an increase in activity was also observed in regions of Europe, although this did not occur simultaneously (Eisbacher and Clague 1984; Brunsden and Ibsen 1994; Janbu *et al*. 1995; Noverraz *et al* 1998).

In any case, it should be remembered that anthropic disturbances can produce significant changes in the frequency of the slope failures. Analyses carried out in the Cantabria area (Remondo 2001; Remondo *et al*. 2004; Cendrero 2003; Cendrero *et al*. 2004) have shown that the frequency of slides and the volume moved by these was multiplied practically by ten from 1954 to 1997, but it has not been possible to correlate this notable increase with comparable increases in total rainfall, number of storms or annual number of rainy days above certain thresholds, which show no significant changes. On the other hand, there does appear to be a relationship between the degree of human intervention in the territory, through very different actions which, in turn, are related to economic activity as a whole. What this seems to indicate is that human intervention modifies the sensitivity of the surface layer to the action of the main activating agent, rainfall, thus greatly reducing resistance to failure and, therefore, the rainfall threshold needed to provoke slides.

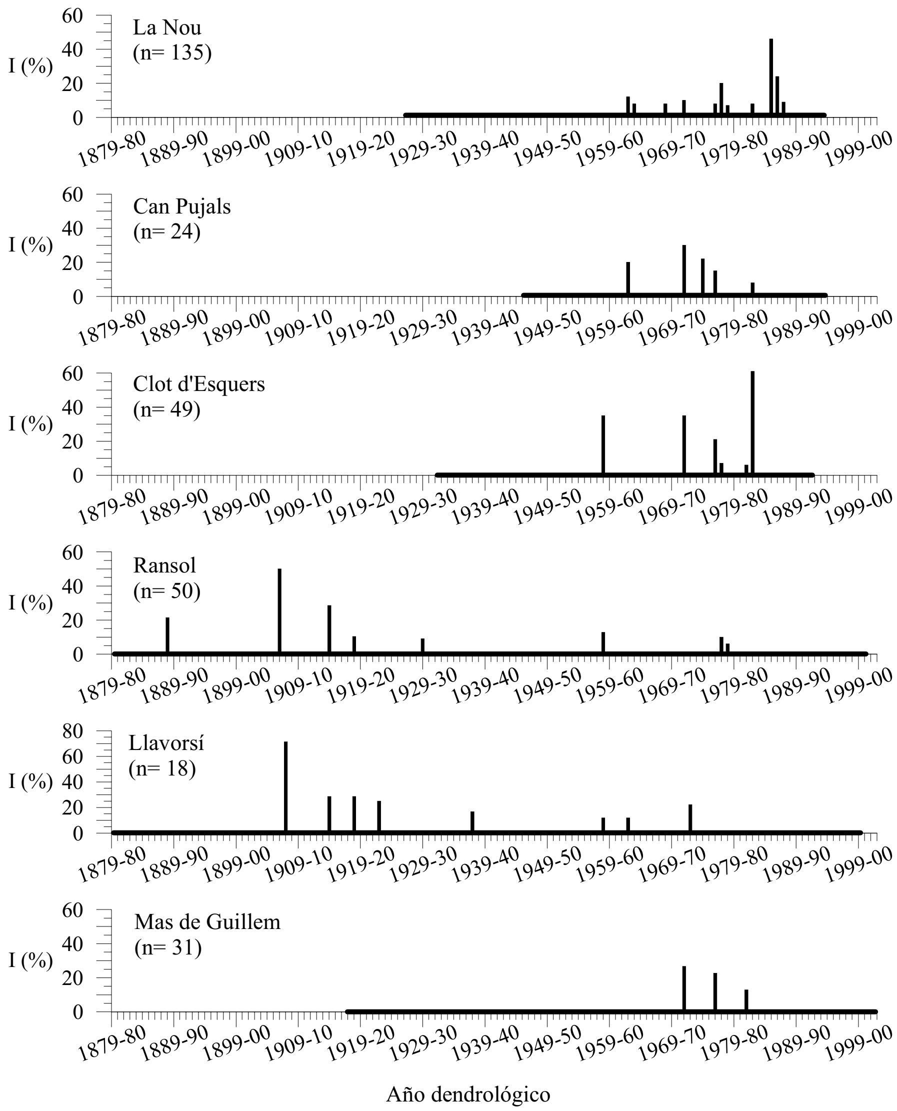

Fig. 12.B.3. *Reactivation events, shown by the vertical bars, deduced from the dendrogeomorphological analysis of six movements distributed throughout the Eastern Pyrenees. I: activity index (percentage of trees sampled presenting response); n: number of trees sampled: the lower thick line indicates the period covered with the sampled trees (Corominas et al. 2004).*

Few data are available in Spain referring to time series that directly inform us of the activity of snow avalanches. In Catalonia, the region where first started the systematic collection on snow avalanches and their hazard (Vilaplana and Martínez 1996), the data collected by ICC (Catalonian Cartographic Institute) provide some idea of the trend. If we consider the climatic factors conditioning the snow layer (temperature and rainfall during the winter season), the thermopluviometric interpretation indicates that between the 1977-78 (starting date of the snow meteorological series in the Catalan Pyrenees) and the 1986-87 seasons, a balance can be seen in the annual mean temperature and rainfall values in relation to the mean values of the series with some deviation towards colder values. To the contrary, more unbalanced values can be appreciated between the 1987-88 and 2001-2002 seasons, with a tendency to deviate towards warmer values (between 0.5 and 2.5ºC in relation to the average), drier winters alternating with warmer ones.

The ICC database contains a snow meteorological series for the last 25 years. The currently available information on avalanches is very fragmented, and it is therefore difficult to reach conclusions. For the last few years of the information series, this is more accurate, but it covers a non-representative period. In spite of the fact that in recent years there has been more snowfall in spring, no relationship can be established with the activity of avalanches or with the typology of these. In the events of greater magnitude, it cannot be appreciated that snow avalanches show any decrease in favour of melting snow avalanches. No appearance of slush flow episodes has been noted, either, and only one of these has been indicated in the Pyrenees of Lleida (Furdada *et al*. 1999).

12.B.2.2. Slope instability in the past. Relationship with climate

12.B.2.2.1. Criteria for establishing the climatic origin of slope instability compared with other causes

The evidence that rainfall is mainly responsible for the failure of many slopes leads us to question whether the different types of slides are associated with specific climatic signature. We can transfer the question to the present: Does the activity of slides at the present time enable us to establish a clear climatic pattern? What other factors could question climatic interpretations in relation to the activity of slides?

The first studies on the theme (Starkel 1985) suggested a synchronicity in glacial advance phases, of solifluction and of a decrease in the upper tree line, coinciding with intense storms, persistent rainfall, rainy years and greater landslide activity. More complete recent studies, however, show that non-climatic factors often blurry climatic signal (Berrisford and Matthews 1997) and that series of landslides often contain movements of non-climatic origin. For this reason, before establishing cause-effect relationships, a careful selection must be made of the group of slides in order to ensure that only climate is responsible for its activity.

There is no specific type of failure or morphological characteristic in an isolated landslide that irrefutably indicates that it was caused by rainfall or climatic phenomena. Both rainfall and earthquakes cause rockfalls, slides, debris and earthflows and large landslides. In the case of recent slides that have occurred in the last few decades or in the last hundred years, it is initially possible to infer the triggering mechanism, by contrasting their age with rainfall, flooding and earthquake records. This is not feasible in the case of old landslides (several hundreds of years). The triggering mechanism, however, can be deduced on occasions from the analysis of landslide populations. The methods used are based on the presence of different concurring features. To this end, a population of contemporary slides of an established age is needed. The main hypothesis consists of grouping the slides in one same time lapse, which indicates that they share the same triggering mechanism. The type of the landslide population can provide some clues for the identification of the causal factor (table 12.B.3). There is a direct relationship between the spatial distribution of landslides and the triggering mechanism: climate, earthquake, fluvial incision (Palmquist and Bible 1980; Crozier 1991). The first two cause failures that are distributed over large areas. Slides caused by an earthquake, however, tend to adjust to an ellipse which main axis is centred on the fault that has caused them, whereas rainfall causes slides distributed more homogeneously throughout the region. Furthermore, the modal size of slides caused by earthquakes is greater than that of those caused by rainfall. Rainfall episodes can cause isolated failures of large landslides but apparently only earthquakes can cause numerous deep slope failures in a simultaneous manner. Landslides caused by fluvial incision are only found at the foot of the slopes, at the valley bottom.

Other types of slope movements, such as rock avalanches are believed to have been caused by earthquakes (Schuster *et al*. 1992). Seismic inference was also obtained from the widespread occurrence of rockfalls (Bull *et al*. 1994). Rockfalls dated with the use of lichenometry were considered to be the result of earthquake events after calibrating the frequency distributions of the size of the lichens with historic seismic activity.

Tabla 12.B.3. *Characteristics of landslides in relation to climate and earthquakes*.

Type of slide	Seismic cause	Climatic cause
Widespread slope failures	Failures appear distributed around the active fault, constructing an ellipse with its main axis parallel to the layout of this. Large modal size	Failures distributed throughout distant regions Modal size less than those caused by earthquakes
Rockfalls	Simultaneous rockfalls	Associated with freeze-thaw cycles Often caused by rainfall Thresholds not logical
Rock avalanches	Clustering of rock avalanches	Rarely due to climatic causes
Debris flow and shallow slides	Possible if there is a high water content on the slope	Very intense short-lived storms
Earthflow	Frequent during earthquakes	Moderate intensity and long duration to reactivate dormant movements Little rainfall for active movements
Rotational and translational slides	Triggered by earthquakes, usually some days after the event	Moderate intensity and long duration to reactivate latent movements
Large landslides	Clustering of first-time failures	Rarely first-time failures Seasonal or annual rainfall reactivates dormant landslides or accelerates active ones. Complex relationship.

The most characteristic movements caused by climatic factors are debris flow and shallow slides, although seismic causes cannot be ruled out in tectonically active regions. Rotational slides and earthflows are caused both by rainfall and by earthquakes. Attention should be paid to flows (earthflow) as these can remain active for centuries. In this case, the concurrence of these with causal mechanisms is simply a coincidence, although transient acceleration can occur. In such a case it is not possible to establish a relation with the triggering mechanisms.

It should be kept in mind that certain periods with a higher frequency of slides are associated with the erosion of coasts or rivers. Climate has a direct control over river flooding and sea storms, but the continued erosion of the base of cliffs and of the deposits accumulated at the foot of these are what control long-term stability.

Multicriteria analysis techniques (analysis of geomorphological features, stratigraphic relationships, absolute and relative dating) were used in the Canary Isles (Lomoschitz and Corominas 1992; Lomoschitz *et al*. 2002) and in the Cantabrian range (González-Díez 1995; González-Díez *et al*. 1996; González-Díez *et al*. 1999; Jiménez 1997) to group landslides into populations of similar ages.

In spite of the fact that climate is not the only cause of slides, it plays an important role in the resistance of the terrain, through control of the water pressures therein, and it therefore has an important influence, albeit indirect, with regard to landslides triggered by other mechanisms.

12.B.2.2.2. Effects of climatic variability on slope instability based on dated slide series

As has already been pointed out, not all prehistoric slides can be attributed to climatic conditioning factors. The huge lateral apertures of volcanic buildings in Gran Canaria (Barranco de Tirajana gorge) or in Tenerife (Oratava and Güimar valleys) are the result of the sliding of gigantic lava stacks and pyroclasts, during the Pliocene and the Pleistocene and their origin is generally attributed to the seismicity associated with volcanic eruptions, to gas pressure and intruded dykes in the volcanic buildings, to marine erosion, etc

In areas of moderate or low seismicity, the activity of big slides is believed to be associated with rainy periods. In the Pas valley, the spatial distribution and typology of slides, classified according to age, has enabled reasonable hypotheses to be established with regard to their climatic or seismic origin or to fluvial or anthropic intervention (González-Díez 1995; González-Díez *et al*. 1996; González-Diez *et al*. 1999). This allowed for the use of dated slides as indicators of past climate (figure 12.B.4).

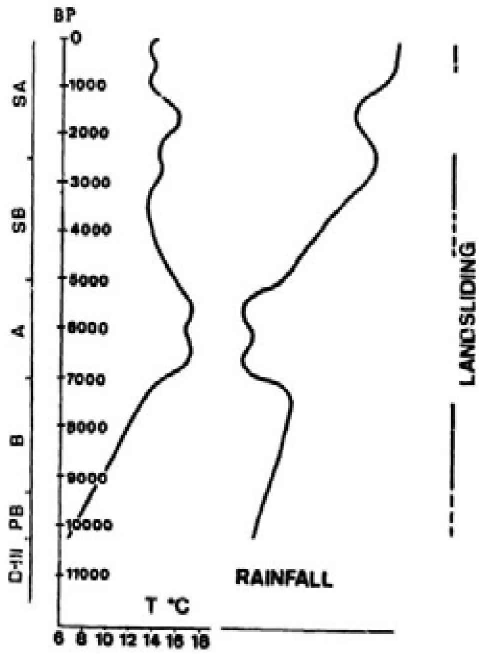

Fig. 12.B.4. *Relationship between rainfall, temperature, and the occurrence of landslides in the Magdalena-Pas Valley, Cantabrian Range (González-Diez et al. 1996)*

Data from the Cantabrian Range (González-Diez *et al*. 1999) indicate that the periods of greater slide activity correspond to the beginning of the last interglacial period (125,000 BP), to the beginning of the glacial thaw, coinciding with a temperature increase (50,000-45,000 BP), in a short interglacial episode (25,000-20,000 BP), coinciding with deglaciation and increased rainfall at the end of the Dryas III (15,000-5,000 BP), coinciding with the Neolithic colonisation and subsequent deforestation and increased rainfall (5,000-3,000 BP), in the second half of the 3,000-200 BP period, especially the XVI-XVIII centuries, a phase in which shipbuilding involved cutting down forests in the region and, lastly, in the XIX century, coinciding with the end of the Little Ice Age and with increased rainfall and human intervention. In the Pyrenees, several phases of this type have also been observed (Moya *et al*. 1997).

12.B.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

Based on scenarios for the Iberian Peninsula (see Chapter 1), four aspects were considered in relation to the effects of climate change on slope stability: (a) an increase in winter rainfall on the Cantabrian coast and the northern basin of the Duero river (b) a decrease in rainfall in absolute terms and a possible increase in the irregularity of rainfall in the Mediterranean Arch; (c) a moderate rise in sea level; and (d) higher temperatures with the consequent altitudinal displacement of vegetation.

With regard to snow avalanches, the study by Glazovskaya (1998) predicts that snowfall and the activity of avalanches on the Iberian Peninsula will not be subjected to changes in the future, but highlights the need for more accurate studies, in a regional context that is better delimited with regard to this theme.

12.B.3.1. Foreseeable changes in the appearance of new failures according to the typology of the movements

New first-time large failures are not expected, due to the absence of big rainfall episodes and to the fact that a rise in sea level will be a factor that reduces the possibilities of an incision of the fluvial network. Only in the Baetic ranges, torrential flooding could favour new failures, due to slope undermining in slopes made of shales. There is much uncertainty with regard to an increase in torrential rainfall. Christensen and Christensen (2003) predict an increase in the frequency of torrential rains during summer months in Europe, although the results for the Iberian Peninsula are very uncertain. Other autors (see Chapter 1), on the other hand, believe that there will be no significant alteration in the degree of torrentiality of rainfall. In any case, an increase in shallow slides, debris flow and rockfalls due to alterations of anthropic origin and to less protection of slopes by vegetation, which will have more adverse climatic conditions with regard to development and which will be affected increased forest fires. Substitution of plant species favours slope failures, especially in those areas in which the autochthonous vegetation is substituted by plants with shallower roots, which provide poorer retention of the surficial formation. In the Los Serranos (Valencia) region, it has been observed that the rainfall threshold capable of causing failures decreased after several fires (Izquierdo and Abad 1997).

Increased temperature in mountain ranges will favour the increase in rockfalls at higher elevations which, at present, are protected from temperature changes by the layer of snow, practically from December to May. The melting of the permafrost could cause an increase in debris flow. Although no data are available on the distribution of permafrost, the area of this, in the very best of cases, is very limited and restricted to the higher parts of the Pyrenees-Cantabrian Range and of the Baetic ranges. Finally, on rocky coasts, the rise in sea level will favour erosion and failure of cliffs consisting of weak rock formations (flysch, clays and sandstone, lava and pyroclasts, etc.). In the XXI century, however, the latest forecasts reduce this rise to barely a few decimetres (Sánchez-Arcilla *et al*. 2004), which will limit the occurrence of new failures.

For snow avalanches, the report on climate change in Catalonia, drawn up by the *Consell Assessor per al Desenvolupament Sostenible* (advisory council for sustainable development) *of the Generalitat de Catalunya* (Catalonia regional govt.), predicts that a temperature increase will cause the altitudinal displacement of the snow layer in the Pyrenees, which will rise to above 2,000 m and which will show a decrease with regard to total area. We can consequently expect the area exposed to avalanches to decline. The same report warns that, based on certain global studies dealing with rainfall prediction, we can expect a decrease in the number of rainy days at our latitudes, and an increase in global rainfall, which implies increasingly intense events. With regard to the typology of the avalanches, greater frequency of snow melting avalanches is to be expected, and eventually, of slush flow avalanches. In any case, we require many more data on the activity and types of avalanches in all Spanish mountain ranges, in order to make any type of predictions.

12.B.3.2. Changes to be expected in the magnitude and frequency of reactivation episodes, according to the different types of movements

The immediate consequence of greater frequency of intense rainfall will be an increase in shallow slides, debris flow and rockfalls. In the medium-long term, however, the rate of appearance of failures is also limited by the availability of movable material on the slope (Marqués *et al*. 2001). Two high-intensity rainy events very close to each other can have very different results. The first event can transport large amounts colluvium and weathered soils from the more susceptible slopes. The slopes that have been purged will not suffer new failures because of the lack of material. Infill of the hollows with new material and weathering could require several decades.

Increased winter rainfall in the Cantabrian Range and the northern Duero basin would favour the reactivation of some big rotational slides and earthflows, especially if the increased rainfall is accompanied by river floods capable of sustaining the erosive action of the meanders on the river banks. In the rest of the Peninsula, the loss of seasonal and interannual rainfall will mean that some large movements will become dormant landslides. The exceptions will involve large landslides associated with particular geological context such as landslides fed with large amounts of groundwater in the event of intense downpours (Pont de Bar, La Coma and Gòsol in Lleida or Intza in Navarre) or those situated on riverbanks subjected to extraordinary floods.

Relict slides, in particular dismantled ones and ones disconnected from the current drainage network, as occurs with the oldest ones (Upper Pliocene- Mid Pleistocene) in the Tirajana basin (Lomoschitz *et al*. 2002) have very little chance of reactivation.

12.B.4. MOST VULNERABLE AREAS

As a consequence of what has been indicated in the previous sections, the big slides in the Cantabrian Range are the most susceptible to reactivation, especially in the Pas, Besaya, Magdalena-Pas and Miera valleys, which contain clusters of large landslides and earthflows. In the remaining mountain ranges, the reactivation of large movements will only occur in particular contexts (areas with an extraordinary supply of groundwater, areas of river erosion).

If torrential rainfall becomes more frequent, the increase in shallow slides, debris flows and rockfalls will occur in practically all the mountain ranges, even in the Cantabrian environment. However, in the Central Range and in the Mediterranean sector of the Iberian and the Baetic ranges, there will be less increase due to the calcareous nature of the rock formations and the scant current cover of the soils susceptible to failure. On the other hand, in the Pyrenees and the Coastal Ranges of Catalonia, a significant increase is to be expected due to changes in vegetation.

A rise in sea level, along with the frequency of sea storms, will cause undermining, fall and sliding of the terrain, especially in rock cliffs made up of soft rocks, such as the Triassic and Miocene formations of the northern coast of Majorca (Banyalbúfar, Valldemossa), the Cantabrian coast (flysch in Zumaya, Triassic in Asturias), lava flows stacks on the Canary Isles and, to a lesser degree, the fractured rocky massifs on the Costa Brava and the Costa del Sol.

12.B.5. MAIN ADAPTATIONAL OPTIONS

The impact of increased surface slides and debris flow can be mitigated, partly through policies aimed at the reforestation of slopes and the maintenance of species better adapted to the conditions of the environment. The growth of forests also constitutes a clearly sustainable element for protection against rockfalls (protection forest). Priority should therefore be given to reforestation and fire-fighting policies in the future.

The best adaptational tool involves town planning and land planning that takes into consideration and avoids, as far as possible, development in the areas most susceptible to slope instability.

Public works, especially related to roads and railways should consider construction procedures aimed at avoiding the reactivation of large landslides. To this end, there is a wide range of measures, ranging from minimising the cutslopes to be excavated, reducing overload on slopes (light embankments), contention works (walls and anchoring systems) and drainage systems.

It will be very difficult to establish protection measures against erosion and undermining of coastal cliffs, except in very justifiable specific cases for which measures are economically feasible. Likewise, only those large slides threatening property and infrastructures of value could be corrected and contained.

12.B.6. REPERCUSSIONS FOR OTHER SECTORS OR AREAS

From the socio-economic point of view, both the increase in snowfall elevations and the displacement of snowfall to springtime, will cause losses in winter tourism during the start of the winter (Christmas and new year).

The hydrological regimes of rivers flowing from high-mountain basins could be affected by the delay in the snow melting period, whereas the possible increase in the sediment load in suspension could accelerate the clogging process in reservoirs, reducing the capacity of these, with the consequent implications for hydroelectricity production and in water supply.

12.B.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

Predictions of the future behaviour of slopes are based on the different scenarios considered in the use of available climate change models. At present, these scenarios present great uncertainty with regard both to the area distribution and the frequency of irregular rainfall on the Iberian Peninsula. In this respect, in spite of the fact that increased sea temperature should favour storms in the Mediterranean environment, it cannot be ascertained that torrential downpours will be more frequent although some studies in the Alps claim that this will happen (Bader and Kunz 1998). Furthermore, the predicted increases in temperature and rainfall in the Cantabrian range do not correspond with the responses by landslides in the past. Indeed, figure 12.B.4 shows that the phases with the highest temperatures and rainfall during the Holocene were accompanied by a decrease in rainfall and in the activity of large landslides. As climate models allow for better definition of the rainfall regime on the Iberian Peninsula, the conclusions of this chapter will require confirmation.

There is still great uncertainty with regard to the response to rainfall episodes of both large and small landslides. In spite of the fact that, in scientific literature, different rainfall thresholds have been proposed in relation to the triggering of shallow landslides, these vary greatly depending on the geologic, morphological and climatic conditions of each region. Critical rainfall thresholds have been proposed in Spain for the Eastern Pyrenees, but they still need to be established for the rest of the territory. Furthermore, there is no available knowledge of the hydrological response of most active or dormant large landslides distributed throughout the main mountain ranges.

12.B.8. DETECTING THE CHANGE

Detection of change is related to increased frequency, depending on the type of movement, of the first time slope failures and reactivation episodes.

In the Mediterranean area, the change will be evidenced by the increased frequency of high-intensity rainfall and, consequently, a higher number of debris flows and shallow slides. The increased activity of these events in the last twenty years might be due to this, but we must remember that greater knowledge and interest now exist in relation to these phenomena, which could previously have gone unnoticed.

The increase of the frequency of wintertime reactivation of earthflows and large slides along the increase of both sea storms and the instability of sensitive coastal cliff, would be indicators as well.

12.B.9. IMPLICATIONS FOR POLICIES

12.B.9.1. Environmental policies

The increase in surface slides and debris flow as a consequence of the greater irregularity of rainfall involves the direct supply to the water course of the material mobilised and the erosion of the landslide scarps made up of colluvium and clay formations. As a consequence there will be a significant increase in solid load in suspension in the water course, with the resulting decrease in quality and possible reservoir clogging downstream. For example, in the Vallcebre area, large badlands provide 13% of the sediment load in suspension in the upper basin of the river Llobregat, whereas the area of this only occupies 4%. In this basin, 50% of the solid load is supplied by the badlands, which take up 3.7% of the area, and 32% of the load results from the erosion of spoil tips which take up 4% of the area. Mean annual erosion is 1,000 Tn/km^2/year (Balasch 1986; Clotet and Gallart 1983). In this basin, landslide volume is 20 times the volume of sediment exported annually from the basin, whereas the large Vallcebre slide involves 500 times more.

Large snow avalanches destroy forest throughout large areas of the Pyrenees. As an example, between February 5th and 8th 1996, in the Aigüestortes and Estany de Sant Maurici National Park, 30 big avalanches were counted, that damaged the forest and destroyed an estimated total of 97 hectares of forest. A decrease in the number and magnitude of avalanches would influence the spread of forests.

12.B.9.2. Policies related to risk management

At a general level, there is serious need of a complete and updated inventory of unstable areas. It is also vital to draw up maps of susceptibility, hazard and risks in the most sensitive areas, especially the inhabited ones or those subjected to greater development.

We must avoid situating sensitive facilities (schools, hospitals, etc.) and dangerous industries in areas susceptible to slope failure or reactivation.

In some large slides in inhabited areas, risk prevention and mitigation strategies should be developed. On one hand, if feasible, protection and contention works should be implemented. If this were not possible, there would be a need for early warning devices and evacuation procedures for emergencies.

12.B.9.3. Infrastructures and construction works policies

Construction works for big infrastructures (motorways, railways,...) should be designed with great caution to prevent them from cutting through potentially unstable areas. Infrastructures the breakage of which could cause serious environmental damage (e.g. oil pipelines) should also avoid dangerous areas or design them carefully.

Form the socio-economic point of view, both the rise in snowfall elevations and the displacement of snowfall to springtime could cause losses in winter tourism at the start of winter (Christmas and New Year) as can be already observed in the Swiss Alps. The hydrologic regimes of rivers flowing from high-mountain basins could also be affected by the delay in the snow melt period.

12.B.10. MAIN RESEARCH NEEDS

12.B.10.1. Response of the different types of slope movements to present climatic variability in the different regions of Spain. Behaviour models

There is a crucial needs for an inventory of currently active, latent, sleeping, relict, stabilised, etc. slides. This inventory should also consider large landslides in particular geologic contexts.
The relationship between rainfall and slides is very dependent upon local geologic conditions and regional climatic conditions. Rainfall thresholds at which slides are started should be defined for the different regions and typologies of failures.
With regard to snow avalanches, there is a pressing need to consolidate preventive strategies aimed at mitigating the risk (Vilaplana 2001). In this respect there is a fundamental need to establish a general inventory of avalanches in Spain (Martí *et al*. 1995; Ferrer *et al*. 2000) that deals with two aspects: cartography and the characterisation of avalanche areas throughout the territory exposed, and the establishment of a snow meteorological and avalanche database linked to a network of mountain stations.

12.B.10.2. Response of slope movements to past climatic variability in different regions of Spain

The future behaviour slides can partly be predicted, thanks to the observation of responses by slopes in the past. There is a need to complete historic and prehistoric series on slope failures and reactivation episodes. This task also requires improved techniques for reconstructing series of old slides, as well as improved analysis of the relationship with climatic situations (extreme rainfall events, persistent rainfall events).

12.B.10.3. “Downscaling” of the situations projected by Climate Change models

Although slope instability can, on occasions, occur in a generalised manner throughout a region, it is a local phenomenon that depends on the amount of rainfall collected in the closest surroundings. For this reason, predictions by global circulation models must specify rainfall at detailed scale. Analysis of downpours in the last few decades indicates significant variations in rainfall in mountain areas, where most slope failures occur.

12.B.10.4. Improvement of hydrological models and mechanisms of slope movements for reproducing the effects of Climate Change

In large slides it has been seen that no simple relationship can be established between rainfall and slide activity. Different hydrological and mechanical models have recently been developed which enable the behaviour of complex landslides, with different materials and hydrological-mechanical properties, to be studied when both climatic and geomechanical conditions are well known (Laloui *et al.* 2004). It is precisely the large landslides that pose the biggest threat in the event of reactivation. It is therefore necessary to improve existing models with the help of monitoring data of the landslides. The hypotheses and predictive capacity of the tools used could thus be validated.

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12. IMPACTS ON NATURAL HAZARDS OF CLIMATIC ORIGIN

C. FOREST FIRES RISK

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ABSTRACT

In Spain, there are more than 20,000 forest fires every year, affecting over 150,000 ha throughout the whole country. These fires occur mainly in summer and are caused by people, accidentally in most cases. Fires are favoured by the presence of inflammable vegetation and dessicating climate conditions (high temperatures, low relative air humidity, drought). In Spain, fires have been more numerous in conditions of high temperatures or fire danger rating indices and low rainfall, with relatively rare extreme situations beeing more important than the average ones.

The fire danger rating indices, based on small number of meterorological variables are good predictors of fire occurrence. Fire danger increases from West and North to East and South, the probability of large fires also increasing in this direction. The greater the danger, the higher the variability in the size of the fires, and this becomes less predictable depending on climate.

With climate change there will be an increase in temperatures and in soil dryness, and especially in the frequency of water scarcity, which will cause greater desiccation of live and dead fuels and, therefore, increased flammability. On the other hand, in areas the become arid fuel accumulation will be reduced.

During the XX century, the fire danger rating index has constantly risen, and will continue to do so in the XXI century. There will be greater incidence in time of high danger zones, the duration of this during the year, and of extreme danger situations. There will probably be a greater frequency of fires with these increases. There will be an increase in ignitions caused by lightning.

The abandonment of marginal lands will continue. The more mesophytic vegetation will be replaced by a more xerophytic one. More burnt surface area will lead to more shrubland vegetation. In short, there will be an increase in flamability potential of the territory. The most vulnerable areas will be in the North of Spain, in high mountain or plateau areas, as these will be exposed to a more adverse fire regime than the present one.

The reevaluation of the fire-fighting policy, the inclusion of the fire danger associated with a determined use, an improvement in the surveillance and early-warning systems, and better training and information for the public are some of the adaptive options for mitigating adverse impacts. Management schemes based on the total exclusion of fire must be modifed. Fire must be incorporated as a management tool in order to reduce fire hazard in a given area.

The production potential of the forestry sector will diminish, as will the risk of soil and biodiversity loss. The residential use of forest and wildlands will be affected.

Major unknowns are how the number of fires will change, the role of landscape in determining the area burnt, the risk associated with the recreational use of the territory and the importance of processes that increase vegetation necromass, such as pests or droughts.

The detection of change in fire occurrence requires the maintenance of the EGIF database on forest fires in Spain. The change in the fire regime will affect fire-fighting and prevention policies, and policies dealing with soil conservation and desertification, biodiversity conservation and land use. The most relevant research needs involve establishing the interaction between drought, fire danger and the response of the vegetation to fire, and availing of climate and vegetation scenarios with appropriate spatial and temporal resolution.

12.C.1. INTRODUCTION

12.C.1.1. Background on climate and fires

Forest fires are one of the most important factors influencing the structure and functioning of many terrestrial ecosystems. They also are responsible for the release of large quantities of CO2 and other gasses to the atmosphere (Prentice *et al*. 2000). At present, over 1000 Mha are burnt every year, mostly in tropical savannahs, and in tropical and boreal forests (Levine 1991). Mediterranean areas and those in southern Europe also have a high occurrence of fires (Vélez 2000a).

In the past, there has been a close relationship between climatic variation and forest fires (Clark 1988; Carcaillet *et al*. 2002), so that these have been more frequent in hot periods than in cold ones. There is increasing knowledge in Spain of the relationship between past climate change, vegetation and fires, in particular after the Holocene (Peñalba 1994; Goñi and Hannon 1999; Carrión and van Geel 1999; Santos *et al*. 2000). During this period, Spain's vegetation was extremely dynamic, with changes associated with climate. There is an intermittent presence of charcoal in sediment records. The relationship between climate and fires can be clearly seen in the reconstruction in the Sierra de Gádor mountains: increasing aridification following the mid-Holocene led to an increase in the frequency of extreme fire events (ranging from peaks of 300-400 years to others of 100-200 years), and to a change in the vegetation (Carrión *et al*. 2003). The appearance of man caused an increase in fire frequency in most of the sites studied, and a change in the predominant vegetation.

Although historic references to forest fires are commonly found (Lloret and Mari 2001; Pausas 2004), or to regulations associated with them (Vélez 2000a), a reconstruction of the fire regime in Spain based on historic data has not been possible, and even less so if we refer to climate-related changes. Furthermore, the lack of old forest has hindered the establishment of the degree of recurrence of fires. Scar dating on *Pinus pinaster* in the Sierra Bermeja mountains shows a high frequency of surface fires during the end of the XIX century and the start of the XX century (recurrence of 11-35 years), which was probably associated with grazing (Vega 2000).

12.C.1.2. Temporal trends in the number and area burned by fires in Spain

The number of forest fires recorded in Spain has increased during the past decades, just levelling off lately. The tendency of annual surface area burnt is different. Form the 60s to the 80s, the area burnt was multiplied until it reached the current situation, which is characterised by a large annual variability (Fig. 12.C.1). Although part of this change is due to the fact that the old statistics dealt with publicly managed land, the fires have spread in time from a limited number of points to practically the whole of Spain (Moreno *et al*. 1998). There are, however, a few areas, in the Northwest, Centre, Levant, South and Southwest where they are particularly abundant (Fig. 12.C.2).

The origin of these fires is mainly human (>95%), Galicia being one of the regions with the highest number of deliberate fires. There are few fires caused by lightning, but they do occur in some areas: in the province of Teruel more than half of all fires are caused by lightning; one third of the area burnt in the regional autonomies of Valencia, Castilla-La Mancha or Aragón from 1989 to 1995 was caused by lightning; a major part of fires larger than 10 000 ha were caused by lightning (Vélez 2000b). The fires occur mostly in summer, although there is a certain variability throughout the country and in relation to the cause of the fire. Thus, whereas fires caused by lightening are clearly limited to this season, they can be caused by man at any time of year (Fig. 12.C.3).

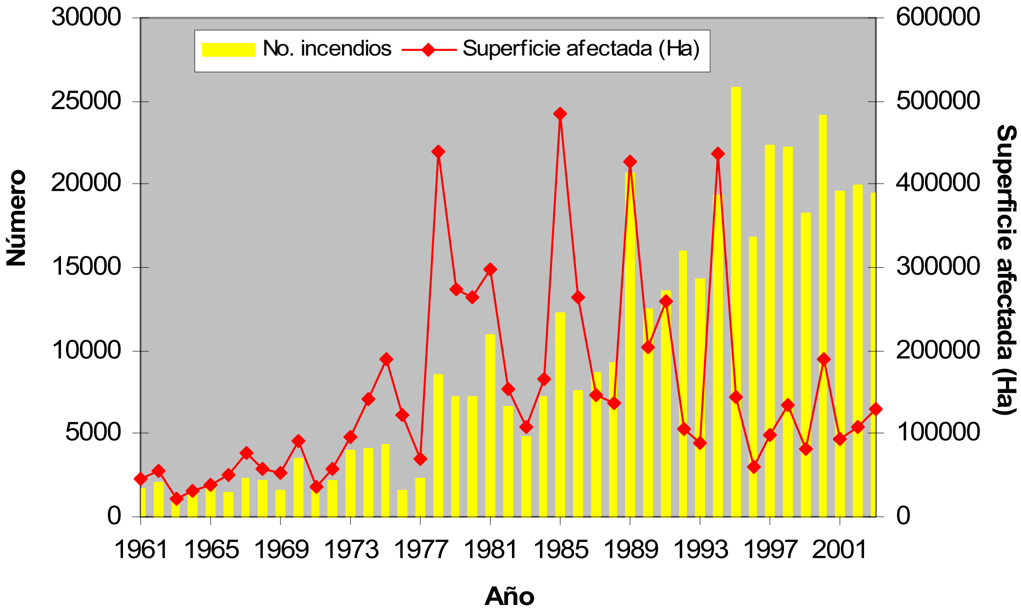

Fig. 12.C.1. *Annual number of fires (bars, yellow) (number) and area affected by these (line, red) (ha) in the last few decades. Source: EGIF (DGB, MIMAM) and own ellaboration.*

Furthermore, the type of landscape burnt has been changing over time: in the last few years, there has been a dominance of unwooded areas over forests (Fig. 12.C.4). In the forests burnt, conifers dominate, in particular *Pinus halepensis* and *Pinus pinaster*. The average age of the trees burnt barely reaches 25 years (Moreno *et al*. 1998).

12.C.1.3. Scope of fires in Spain

On average from 1991 to 2002, the area burnt annually was 0.55% of total forest area. This means that if the whole forest area were to be equally affected, it would take 180 years for it to be burnt once. This overall figure conceals the fact that there are large differneces in the recurrence time. In 100 years some areas will be expected to burn many times and others will not burn at all (Vázquez and Moreno 1998). Great losses are caused by fires, either of primary products or of environmental values, and in particularly bad years these can exceed 400 M€ in direct profits and 1000 M€ in total profits (EGIF, DGB, MIMAM). Furthermore, the costs related to combating and preventing fires and restoring the damage are very high. If, for example, we take the Generalitat de Valencia (regional autonomy), in the 90s, 9.34 M€ was invested, most of this (77%) in extinction, and this figure rose to 60.77 M€ in 2000 (65% in extinction). This increase by almost 7 times for extinction and by 10 times for prevention had not an equivalent effect in reducing the area burnt (Vega García 2003). Parallel to the regional administrations, the central government invests large sums, an annual average in the last decade of 50 M€, 35% in prevention and 65 % in firefighting (DGB, MIMAM). This indicates that the capacity to control the areas affected by fire is limited, and that bigger investments do not necessarily mean greater effectiveness. In this sense, policies emphasising prevention aspects, with specific plans for prevention through ownership, as is implemented in certain Regional Autonomies, might be more effective.

12.C.2 SENSITIVITY TO THE PRESENT CLIMATE

12.C.2.1. Factors controlling forest fires

Climate, vegetation and fuel

Climate determines the dominant vegetation in a region (Rivas Martínez 1987) and therefore the amount and kinds of fuels available to carry fires. Consequently, the climate-vegetation relationships tend to be good ones (Moreno *et al*. 1990, Fernández Palacios 1992; Gavilán and Fernández-González 1997; Ojeda *et al*. 1998). In general, in Spain, the mature vegetation made up of deciduous trees dominates in the rainier areas, whereas that made up of evergreens does so in the dry areas. There is a scarcity of mature natural vegetation in our country, due to the intense use thereof, and the natural vegetation more frequently comes from secondary succession or reforestation. The flammability of this secondary vegetation is, in many cases, greater than that of the mature natural vegetation. This is particularly so when pioneer vegetation is dominated by species that accumulate fine fuel and necromass. Because of this, the relationship between the flammability of the vegetation and climate is not simsple. During the final part of the XX century, the dominant vegetation has increased its potential flamability as a result of less exploitation and reduced grazing, and to the abandonment of marginal croplands and lack of use of wood as fuel (Vélez 2000a). Furthermore, the vegetation that grows after plantations of conifers or broadleaf species like eucalyptus have been burnt, is often highly inflammable.

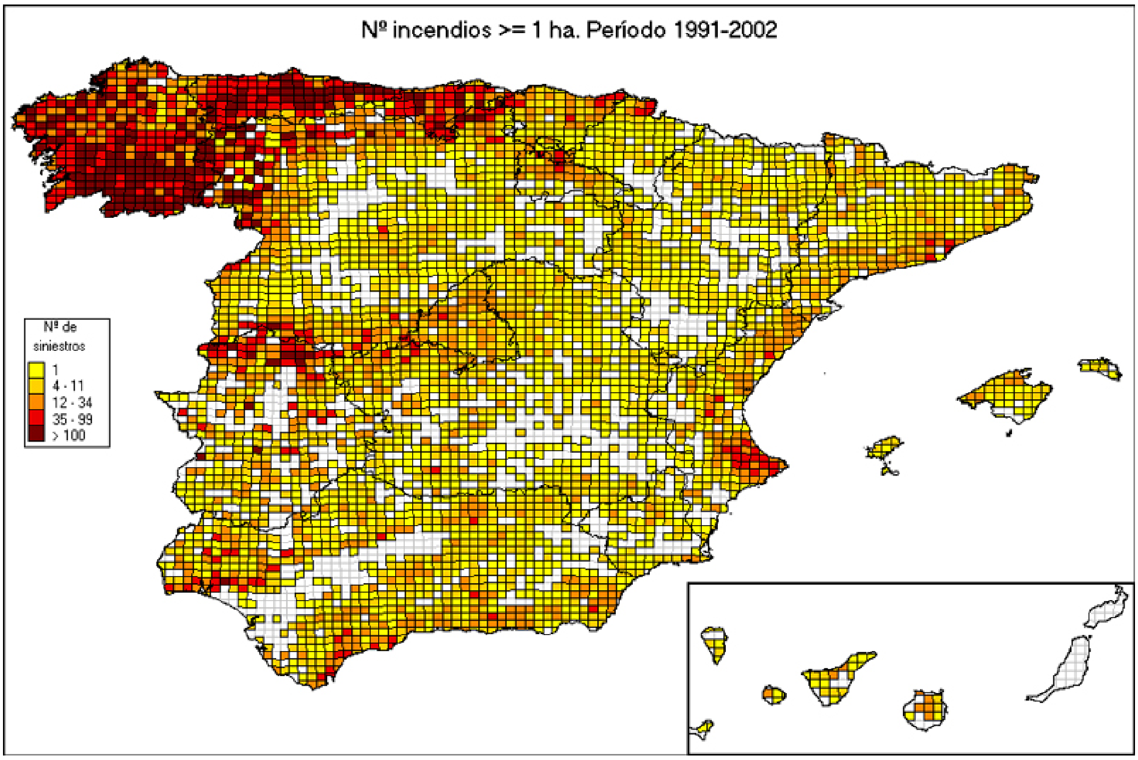

Fig. 12.C.2. *Distribution of forest fires equal to or bigger than 1 ha in Spain during the 1991-2002 period. Source: DGB, MIMAM.*

Meteorology

The meteorological variables most influencing the development of fires are temperature, wind speed, air relative humidity and stability of the atmosphere. In the stable and dry summer environments the energy received from the sun increases temperature and reduces the relative air humidity. Both variables (temperature and relative humidity of the air) control the hydration state of dead fuels. Wind is another critical element: the speed of the spread of the fire front is directly proportional to wind speed. The most dangerous situations are those involving strong, dry winds. *Föhn*-type winds are particularly critical; these are winds blowing on the leeward side of mountains as a result of the adiabatic compression of the air on blowing down the slopes (Millán *et al*. 1998), and these are the cause of some of the large fires in Spain (Gómez-Tejedor *et al*. 2000).

Fire heats the air, which rises, drawing in cool air towards the base of the fire which provides oxygen to sustain combustion. When there is wind, this effect is augmented on the downwind side by the wind-driven air flow.. The stability of the lower levels of the atmosphere determines the degree of intensity of the local wind caused by the fire. Situations of atmospheric instability favour the vertical movement of the hot air, facilitating the lateral movement of the air towards the fire front. To the contrary, in stable conditions, fires are relatively less dangerous. Thus, with two parameters of atmospheric stability, Díez *et al*. (2000) calculated, to a high degree of accuracy, the daily occurrence of fires in Galicia. The synoptic situations determining the state of the atmosphere are therefore critical for the occurrence of forest fires (Díez *et al*. 1994). These determine atmospheric flow, and, through this, wind, precipitation or lightening discharges, among other phenomena (Gómez-Tejedor *et al*. 2000; González-Hidalgo *et al*. 2001; Goodess and Jones 2002; García-Herrera *et al*. 2003; Muñoz-Díaz and Rodrigo 2003; Tomás *et al*. 2004). Consequently, many fires occur in determined synoptic conditions (Bardají *et al*. 1998). This is similar for the rest of the world (Da Camara *et al*. 1998; Johnson and Wowchuk 1993).

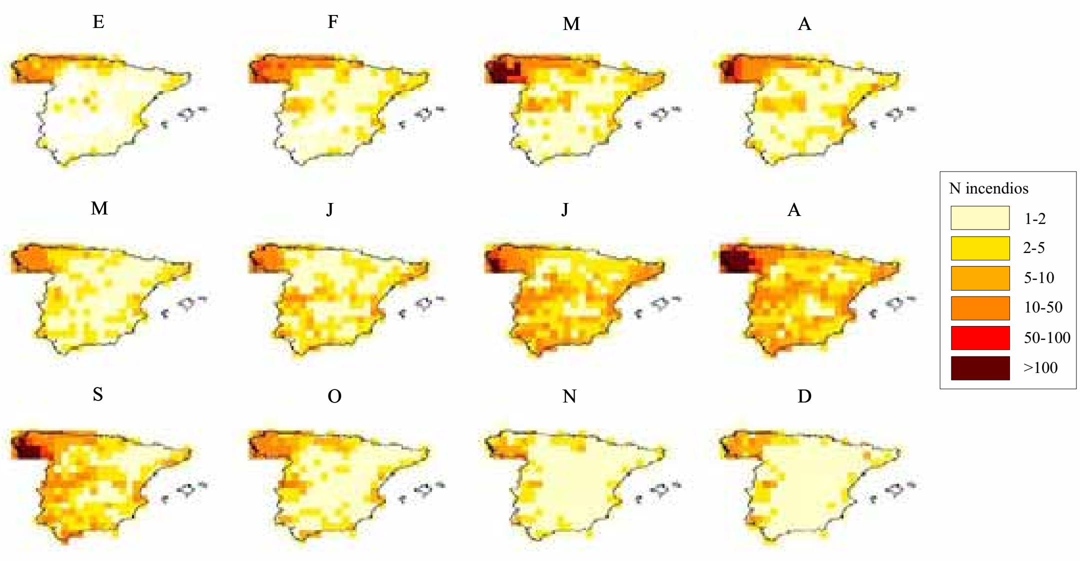

Fig. 12.C.3. *Occurrence of fires on the Spanish Peninsula in the different months of the year during the decade 1990-1999. (The average number of fires per month is shown). (Moreno et al. 2005).*

Fuels

Moisture of fine fuels: The moisture content of live fine fuels varies throughout the year, being maxium in spring and minimum at the end of summer. The moisture content is related to phenology and to the availability of water in the soil, and is therefore well related to drought indices (Viegas *et al*. 2001; Castro *et al*. 2003) (Fig. 12.C.5). This relationship is such that the most important effects take place in the initial phases of soil water deficit. The relationship varies according to species. Thus, pioneer species tend to vary more and to be more closely related to rainfall than the other, late successional ones, which have access to water at greater depths (Moreno and Cruz 2000; Peñuelas *et al*. 2001; Viegas *et al*. 2001; Filella and Peñuelas 2003). The state of the live fuels therefore depends on how much it rains and on when this occurs. Moisture content can also vary with the age of the plant (Baeza *et al*. 2002).

Chemical composition. Apart from water, the chemical composition of plants determines their energy content and flammability. Ether extractives (essential oils, resins, etc.) favour flammability (Trabaud 1976). Forest species experience sharp seasonal variations in chemical content (Elvira and Hernando 1989; Núñez-Regueira *et al*. 1999), which in turn cause variations in their flammability throughout the year (Núñez-Regueira *et al*. 2000).

Moisture of dead fine fuel: The moisture content of living fuels is maintained by the transport of water from the soil, and thus live leaves and branches have relatively high moisture contents even in times of drought. But the moisture content of dead fuels fluctuates widely in response to variation in relative humidty, rainfall, and solar radiation, to name the three most important factors. The spread of fire is very sensitive to the presence of dead fine fuel ($\phi \leq 6$ mm), because it is the most flammable when exposed to heat. In addition, is the one that adjusts most rapidly to meteorological conditions. The moisture content of standing dead fuel varies throughout the year, and is lower in summer. In stable atmospheres, relative humidity decreases with an increase in temperature, and the moisture content of these fuels is therefore maximum at the start of the day, and minimum at the start of the evening. Likewise, the moisture content of the litter depends on meteorological conditions, its exposure to the sun, and also on soil moisture content. The more dessicant the atmosphere, and the lower the soil moisture, the drier the litter will be, which will increase the flammability and combustibility of this, and of the standing dead fuels (Valette 1988; Viegas 1998).

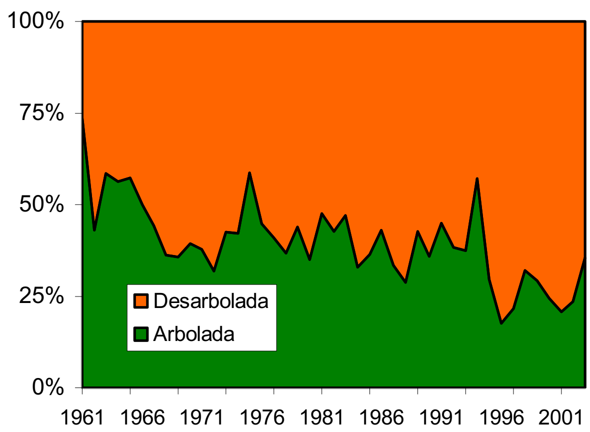

Fig. 12.C.4. *Variation over the last few decades in the type of surface affected by fir (wooded: greeen; unwooded: orange) Source: Anonymous and EGIF(DGB, MIMAM)(own compilation).*

Topography

The spread of fire increases with the angle that the terrain offers to the fire front. An upslope spread is therefore rapid and dangerous. Fires do not occur by chance, but rather are more frequent in certain topographies (Vázquez and Moreno 2001; Lloret *et al*. 2002). Although topography may not change, vegetation can do so, particularly after a fire. This makes the risk in a given area vary in time as the vegetation changes, and according to the topographic conditions of the area in question.

Lightning as a source of ignition

In Spain, the frequency of lightening discharges is related to sea temperature (de Pablo and Soriano 2002; Soriano and de Pablo 2002), and are more abundant when this is higher. Lightening is more frequent in mountain areas (Pyrenees, Iberian System and Central System), with a gradient of abundance from lower (Southwest) to higher (Northeast) (Soriano *et al*. 2001a, b). There is a higher frequency of discharges in summer (Ju, Jl, Ag), followed by autumn (Se, Oc) and spring (My). The number of discharges is related to certain circulatory synoptic types (Tomás *et al*. 2004), and the highest number of discharges is caused by cyclonic situations and by easterly flows. The geographic distribution of fires caused by lightening generally tallies with the distribution of these, but is different in the case of fires caused by man (Vázquez and Moreno 1998).

12.C.2.2. Fire danger

Fire danger is a measure of the likelihood of a fores fire, and is based on temperature, relative humidiy, wind force and direction and the dryness of the fuels (Vélez 2000c; Viegas *et al*. 2000). Thus, fire danger indices are useful in representing the probability of fire in time and space. Plotting one of this (the Canadian Weather Index) for Spain for the 6 critical warm season months shows how fire danger ingrease first in West Central Spain and then spreads eastward and inland along the eastern coast through the summer. The North and Nortwhest, because of thwie cool and moist clime, remain at low fire danger throughout the season of maxium danger. (Fig. 12.C.6). The days with fires, multiple fires or large fires are often more frequent when the fire danger indices are higher (Andrews *et al*. 2003). Consequently, a higher frequency of high indices implies greater probability of the occurrence of this type of fires. The chances of a large forest fire occurring are related to the presence of masses of unstable air and a low moisture content (Haines 1988). As has been stated, the occurrence of fires in Spain has been related to climatology, and has varied according to areas and ignition sources (Vázquez and Moreno 1993) (Fig. 12.C.7). What appears to be more critical than the mean values of a determined variable or index, however, are the extreme situations, that is to say, the number of particularly hot days, or the time elapsed since the last rains (Vázquez and Moreno 1993; Piñol *et al*. 1998; Pausas 2004).

Fire danger indices are based on climate, but because humans can start fires at any time of the year it is possible to have fires even when fire dange index is not high. Vázquez and Moreno (1995) found that the fire season, considered as the period in which 50% of the fires of a given year occurs, or in which a similar area is burnt, is longer in the Levant than in the Central region, but not than in the Northwest. This is contrary to what might be expected based on the duration of high fire danger situation. Furthermore, in the Northwest, the years with a greater number of days with higher temperatures the area burnt was bigger. However, the fire season was shorter, not longer. These relationships were in part related to the source of ignition, being deliberate fires the ones that most closely reflected this pattern. Consequently, the fire-alert season may not necessarily determine the fire season. In those areas dominated by deliberate fires, it is the cause of the fire that can determine temporality.

12.C.2.3. The size of the fires

The meteorological variability of Spain’s climates (see Chapter 1) affects the annual distribution of the size of the fires, so that these are more unequal when annual meteorological variability is greater. Thus, in the Levant, a small number of fires often burns a high percentage of the area burned during the year. This percentage is lower in the Northwest. The annual variability of the distribution of fire sizes is also greater in the Levant than in the Northwest. Besides, the degree of prediction of the parameters describing the shape of the fire-size frequency distribution is lower then annual climatological variability is higher (Vázquez and Moreno 1995) (Fig. 12.C.8). In other words, in these trhee areas of Spain studied, those having a more variable climate produced fire-size frequency distributions that were more unequal, with greater importance of a small number of big fires over the total area affected by fire in one year. In addition, these fire-size frequency distributions were less predictable as a function of climatic variables.

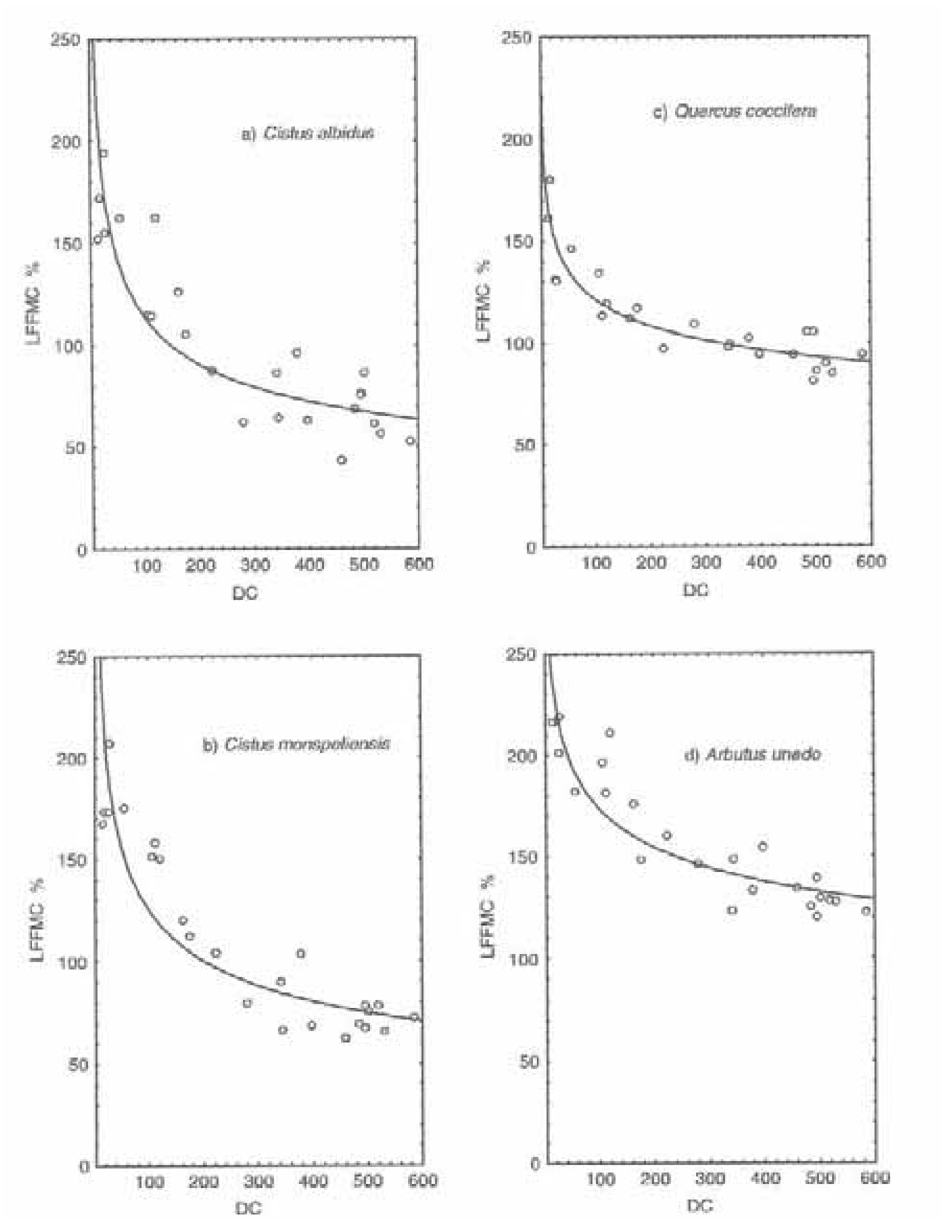

Fig. 12.C.5. Live fine fuel moisture content (LFFMC%) according to the Drought Code of Canadian Fire Danger Rating System in Collserola (Barcelona). Please note the difference between more or less pioneer species. De Viegas et al. (2001).

The size of a fire depends on the ignition source. Deliberate human ignitions tend to produce fires that are less variable in area burned than ignitions caused by lightning. But the degree of difference in fire size for fires caused by different ignition sources depends on the climatic zone.

Paradoxically, ignition source was more determinant on the fire-size frequency distribution as climate-related danger in the area was lowest. In other words, an area with a high climate-related danger (Levant) produced similar fire-size frequency distribution among those fires caused by different sources, whereas other areas with a lower danger (the Northwest) have produced more variable distributions. This is, the ignition source produced higher fire-size variability in a less-fire prone area than in a more fire-prone area. Furthermore, the relationship between the parameters describing these fire-size frequency distributions with climatic variables was low, although in the Northwest (lower danger), the relationship was higher than in the Levant (higher danger) (Vázquez and Moreno 1995).

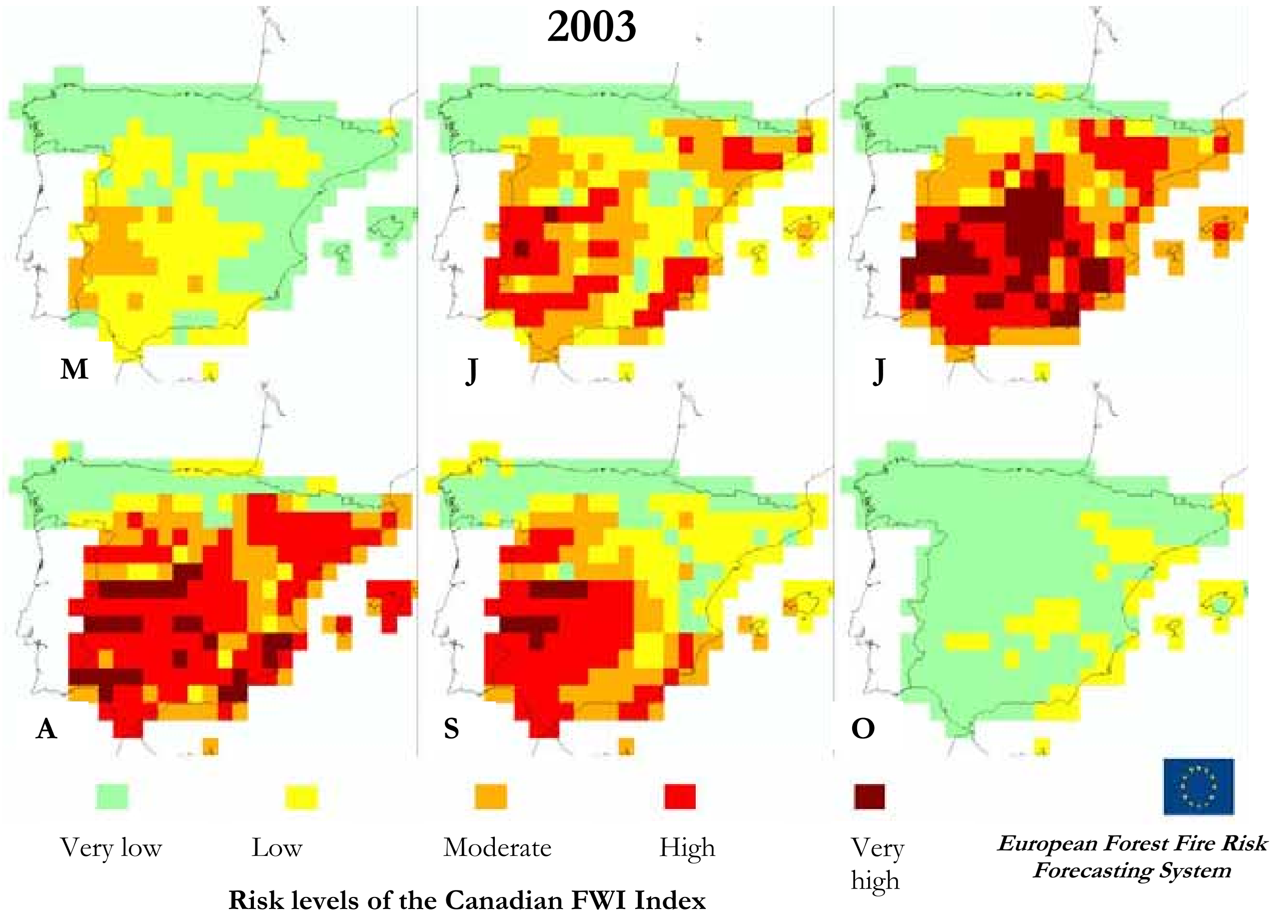

Fig. 12.C.6. Fire danger in Spain according to the Canadian FWI Index from May to October 2003. Map taken from the European Forest Fire Risk Forecasting System, European Institute of the Environment and Sustainable Development , CEC, JRC, Ispra, IT. (http://natural-hazards.jrc.it/effis/effrfs/).

12.C.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

12.C.3.1. Impacts associated with climatology

Temperatures

The tendencies for the future climate of Spain point to an increment in mean temperature of 0.4ºC/decade in the winter and 0.6-0.7º/decade in the summer. Thus, mean temperature increase is higher in summer than in winter. The frequency of extreme termperatures will increase everywhere. The number of days with maximum extreme temperatures will increase in the summer. There are evidences for such tendencies in some areas of Spain (see Chapter 1). The spread of fire is favoured during the day by the temperature increase and the decrease in relative air humidity, which can reduce the moisture content of dead fuels, lowering the threshold for ingnition, making an ignition event more likely to lead to fire. Likewise, night-time temperature increases will be proportionally greater than the daytime ones (Easterling *et al*. 1997). In other words, temperatures during the night will tend to become comparatively higher, with the consequent negative effect on fuel moistening. Assuming that the number of ignition sources and the vegetation do not vary, flammability can therefore be expected to be greater and the fires more frequent, and that once they have broken out, they will spread better and get bigger.

Precipitation

The tendencies for precipitation during this century are not consistent among models, although, they all agree the total annual precipitation will decrease, in particular in spring and summer. (Chap. 1). Precipitation patterns determine the level of soil moisture reserves, and recharge periods are critical with regard to providing the soil with greater stability in water content (Martínez-Fernández and Ceballos 2003). Assuming that total precipitation does not vary, the concentration of this in winter and the consequent lack of rainy days in spring and summer will affect live and dead fuels. This, together with the temperature increase, will cause and increment in potential evapotranspiration (Pausas 2004). Rainfall during the growth period has a great influence on the abundance of herbaceous species (Figueroa and Davy 1991). Rainy springs maintain more surface moisture in the soil, leading to greater development of fine herbaceous fuels, which will subsequently dry out. Temperature increases may cause the development period of herbaceous species to be advanced to early spring or winter, so that, even in a scenario of reduced springtime rainfall, this vegetation may develop well, thus contributing an element of hazard relatively early in the year. This is more relevant in the humid areas which, in time, may become more susceptible to greater summer dryness, which may also appear earlier in the year. Furthermore, less moisture availability in the surface layers of the soil will make the dead fuels in the soil dry out sooner. The lower number of rainy days will keep them dry for a longer time. In pine forests and ecosystems with well developed litter, there will be an increase in flammability and in the period of susceptibility to fire.

The standing vegetation will undergo physiological and phenological changes in response to changes in rainfall patterns. In the first place, the concentration of precipitation in winter, along with the decrease in the number of rainy days during the year, will lead to an increase in the number of days during which plants are subjected to water stress (Martínez-Fernández and Ceballos 2003), with the consequent increase in the duration of the fire season (Rambal and Hoff 1998). The rooting pattern, that is to say, the soil depth that each plant is capable of exploiting, together with its physiological characteristics, determines its level of water stress (Filella and Peñuelas 2003; Martínez-Vilalta *et al*. 2003). The species with shallower rooting systems, which are more susceptible to the availability of surface water, such as certain shrubs as rockrose (*Cistus*), rosemary (*Rosmarinus*), some heather (*Erica*) and other nanophanerophytes, may present higher stress indices (Gratani and Varone 2004) and during extended periods, being more sensitive to changes in the patterns of rainfall than to total precipitation. This will lead to a higher and longer level of hazard in the communities dominated by them (Mouillot et 2002) than in those with deeper rooting systems, like may species of trees (Mediavilla and Escudero 2003a). A lower moisture content in the fine materials will increase their potential flammability thoughout the year, even more so when rainfall is lower and more concentrated early in the year.

In contrast, deep-rooting species may be affected more by decreases in total rainfall. In dry periods, water scarcity may force species to adjust their leaf area (Mouillot *et al*. 2002; Sabaté *et al*. 2002), decreasing the size and number of leaf cohorts that they bear, tending towards a higher proportion of current year leaves than in previous years. In extreme situations, some species may not develop current year leaves (Peñuelas *et al*. 2001). This may affect their flammability, given that old leaves have less water and more energy content (Mediavilla and Escudero 2003b). Furthermore, prolonged drought can cause total or partial death of individuals, with the consequent addition of dead matter. Such situations have been observed in the recent past, like the drought half way through the 90s. During this period, a high death rate of plants was observed, which was widely distributed among the different species, first among those presenting surface rooting (*Cistus* or similar), and afterwards to other deep-rooting ones, although with differences among species that depended on their capacity to tolerate water stress (Peñuelas *et al*. 2001). This effect was more notable on the S slopes than on N slopes, and there were also variations among substrates. It should be noted that in such extreme situations, plant water potentials of certain species, which could be measured even in autumn, could reach extremely low levels (Moreno and Cruz 2000). Recurring drought can cause an increase in standing dead matter, which would increase the hazardousness of the vegetation.

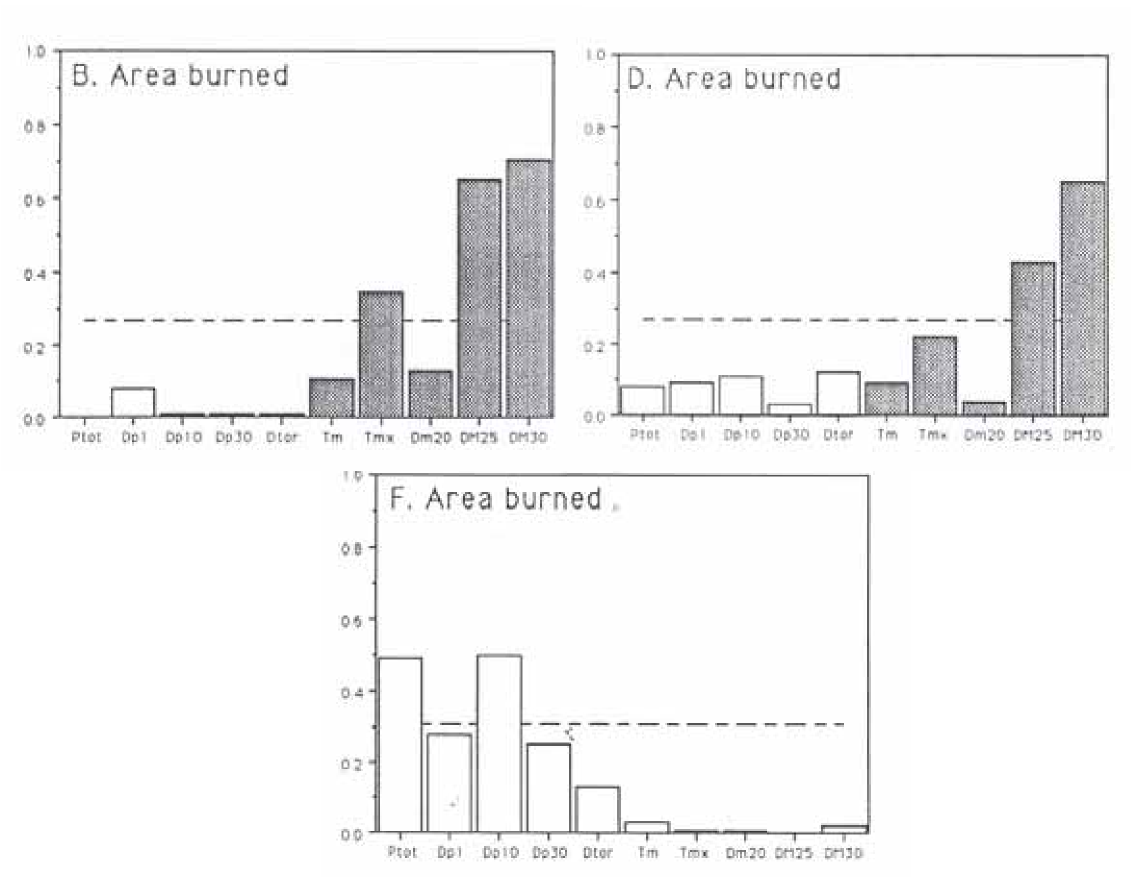

Fig. 12.C.7. *Coefficient of determination (r^2) between different annual precipitation (total rainfall [Ptot] or th rainfall equal to or greater than the values indicated in mm [Dp1, Dp10, DP30], or days with storms [Dtor], respectively) and temperature (mean [Tm], maximum [Tmx] or days with minimum [Dm] or maximum [DM] temperatures higher than the values indicated, respectively) variables and annual burnt area from 1974 to 1988 in three areas in Spain. The dense mesh indicates positive correlations, while negative correlations are shown in white. The broken line indicates the level above which the correlations are statistically significant. From: Vázquez* and *Moreno 1993.*

Wind

Average wind speed will tend to increase. This variation will be less notable in summer than in the other seasons (Chap. 1). Given the important local interactions of this meteor, it is not easy to predict the impact it will have, except that, considering the role it plays in the spread of fire, there will likely be an increase in large fires and in the difficulty involved in extinguishing these.

Vegetation and climate

As climate change materialises, the changes in vegetation it causes will become more evident (see Chapters 2 and 9). In this sense, as the more mesophytic vegetation, which is less flammable, is substituted by another more inflammable one (Peñuelas and Boada. 2003), fire hazard will increase in the areas where this occurs. The same can be said of the increment of horizontal continuity of the vegetation in areas which otherwise would hardly support the spread ofe, such as high mountain areas (Sanz-Elorza *et al*. 2003), or high plateau areas. On the other hand, the aridification of certain areas may caused a reduction in fuel quantity and continuity and thus decrease fire occurrence

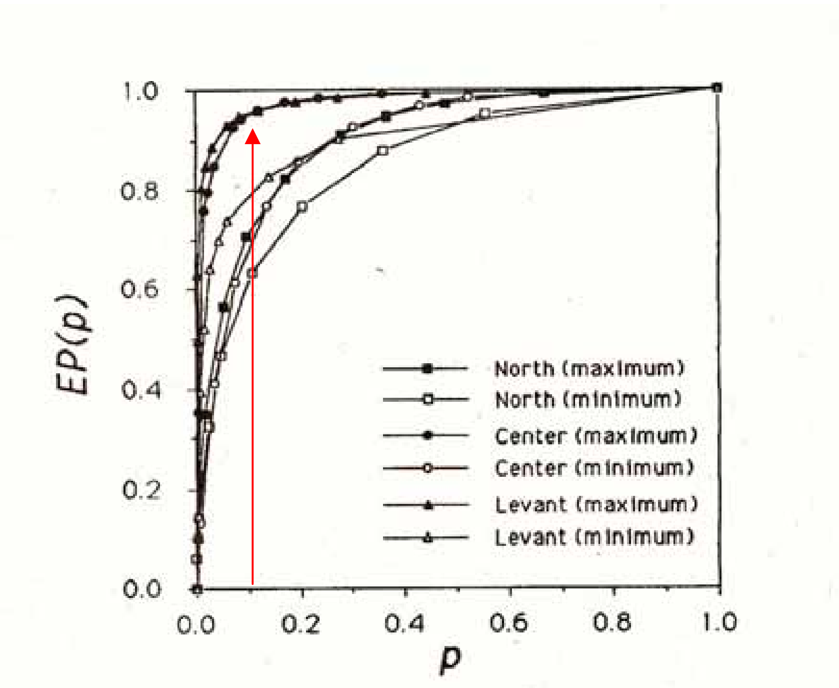

Fig. 12.C.8. *Relationship between the proportion of area burned (EP (p)) by a proportion (p) of fires in three areas of Spain from 1974 to 1988. The proportion of fires (p) is calculated cumulatively starting with the largest fires and ending with the smallest one. Hence, the arrow indicates the proportion of area burnt by the largest 10% of the fires. Please note the greater annual variability in the Levant and Centre than in the Northwest of Spain, and that in extreme years, just 10% of the fires affect over 95% of the area burnt during the year. From Vázquez* and *Moreno 1995.*

Lightning

Predictions based on GCMs indicate that the convective rain fraction will tend to increase, along with the number of lightening discharges (Price and Rind 1994). Lightening will not only be more abundant, but will spread more throughout the year, lengthening the fire season (Price and Rind 1994). Parra (1995) (taken from Rambal and Hoff 1998) demonstrated the existence of a close relationship between the surface temperature of the Mediterranean Sea (SST) and the convective rain fraction (CF) in Barcelona, (CF=4.9SST-38.7; r^2=0.93; P<0.01). The synoptic situations with the highest amount of lightening are the cyclogenic or Eastern ones (Tomas *et al*. 2004). Consequently, the number of fires caused by lightening can be expected to increase in time. The greater frequency of water deficit in the soil means that lightening discharges will become more efficient with regard to causing fires (Nash and Johnson 1996). It should be noted that in the past, most of the fires caused by lightening occurred during very few events, that is to say, consecutive days with storm-related activity (Vázquez and Moreno 1998). The persistence of these situations, resulting from the greater persistence of atmospheric conditions, may be particularly dangerous. The higher degree of abandonment that usually occurs in areas of greater elevation, where lightening is more frequent, suggests that there will be an increase in fuel accumulation, giving rise to fires caused by lightening.

12.C.3.2. Impacts on fire danger indices

As we enter the XXI century, and the predicted climate changes start to materialise, projections based on GCMs indicate a considerable increase in the mean monthly danger index (Fig. 12.C.9). These changes are generalised throughout all the months of the year and will bring the fire season forward in time, even more so as the century elapses and the bigger the change that takes place. It should be noted that all the scenarios predict a considerable increase in fire danger. Given that current fire danger indices are not the same throughout the whole country, the variations will have a greater effect on those areas which are in high danger situations for several months of the year. We can therefore expect acceleration in the number of areas included in the fire alert situations, along with a lengthening of the alert season. Similar scenarios have been described for other parts of the world, the degree of these depending on the climate change predicted (Torn and Fried 1992; Flannigan *et al*. 1998; Williams *et al*. 2001; Brown *et al*. 2004; Fried *et al*. 2004)

Furthermore, an increase in mean fire danger indices implies that, even assuming the distribution of frequencies of situations remains the same, the frequency of extreme situations will increase, but not in proportion to the increase in the average (see Schär *et al*. 2004, for the event in the summer of 2003, or Luterbacher *et al*. 2004, for the increase in the frequencies of extreme events). The duration of these may also increase as a result of the greater tendency towards atmospheric stability. It is difficult to predict the frequency and intensity of these situations, given the inaccuracies of the models. It should be noted, however, that Hulme and Carter (2000) indicate that in the 80s of the XXI century, the probability that every summer will be hotter than one among ten in the last century, is from 65% to 100%, depending on the scenarios used. In other words, every summer will be as hot as the hottest among ten in the XX century practically every year.

Although different GCMs produce different climate changes, even in the more favorable scenario we can expect increasingly frequent situations in which it will be impossible to fight fires in cases of multiple outbreaks in extreme situations. Fire fighting systems have a limited range of action, because, at the very best, they can deal with a situation that is a few times greater than a normal situation. Extreme, severe, prolonged and geographically distributed events force fire fighting services into situations that are far beyond their real capacity to handle, inevitably surpassing the maximum level of effectiveness for which they were conceived. The big fires in 1994 on the Levant or the more recent ones in Portugal in 2003 illustrate what can occur. A scenario of adverse meteorology suggests an increase in the frequency of possible situations in which it becomes tremendously difficult to combat fires.

12.C.3.3. Other impacts

Changes in land uses and in vegetation

Land use has been the most important factor related to changes in vegetation in Spain. The final decades of last century were characterised by an abandonment of the countryside, parallel to an increase in vegetation, either through forestation or due to the development of the natural vegetation (Fernández Alés *et al*. 1992; García-Ruiz *et al*. 1996; Vega García 2003; Duguy 2003; Viedma and Moreno, enviado). The tendency towards the concentration of agriculture in the more fertile areas, the reduction of extensive grazing and an increase in abandoned areas might continue to extend forest and wildland areas. However, analysis of changes in landscapes over the last few decades in certain areas shows that the biggest change might have already occurred. But changes in rainfall and temperatures will reduce the production potential in many areas, which could affect abandonment processes (see chapters 2 and 9). The loss of economic value in some woodlands due to lack of competitivenes with other areas can stimulate the abandonment process.

Other important changes will result from the vegetation that develops following fire as, in many cases, the burning of old pine forests generates shrublands or pine forests that are burnt before reaching reproductive maturity, so that it is the shrublands that emerge (Faraco *et al*. 1993; Vallejo and Alloza 1998; Valbuena *et al*. 2001; Lloret *et al*. 2003; Pérez *et al*. 2003, Rodrigo *et al*. 2004). Given that the place where fires occur does not depend on chance, but rather on specific situations, the changes in values caused by the different type of vegetation will probably involve less effort, both with regard to prevention and to alertness, which could accelerate the fire cycle (Trabaud and Galtie 1996). It has been established that in certain areas (Sierra de Gredos mountains), once pine forests have been burnt, they burn again more rapidly (Vázquez and Moreno 2001). This could lead to changes in the landscape, causing an unequal distribution of the vegetation, with areas dominated by shrublands, more susceptible to exposure to ignition sources, and other forested areas, more distant and inaccessible. Precedents of this process have already been described (Mouillot *et al*. 2003). Furthermore, simulations of increased frequency of fires as a result of climate change indicate a gradual dominance by shrublands (Pausas 1999; Mouillot *et al*. 2002).

Situations of increased frequency of fires will become possible if ecosystems are sufficiently fertile to produce the nutrients required for vegetation growth. The establishment of more favourable climatic conditions in mountains and on plateaus could increase vegetation growth, accelerating the previously described process. Imbalances, however, might be expected between nutrient inputs in the inter-fire interval and losses thereof due to fire, which would lead to decreased fertility of the system (Moreno 1999), resulting in a decrease in the generation rate of the vegetation (Díaz Delgado *et al.* 2002).

Theoretically, if the occurrence of fires is limited by fuel (Minnich 1998), we could expect this process, even in the worst possible conditions predicted, to cause a decrease in the incidence of fires, due to the lack of fuel resulting from frequent fires. Higher fire-fighting efficiency would add to this process (Piñol *et al*. 2004). The theory, however, that fires are mainly controlled by weather conditions appears to be more consistent (Moritz *et al*. 2004). In this case, and under conditions of greater danger, an increasingly negative impact of fires is to be expected in many areas, which would be subjected to fires even in early stages of regeneration (Vázquez and Moreno 2001), with the consequent risk of loss of soil fertility.

Changes in human ignition sources

We cannot establish how situations caused by climate change will affect the people deliberately causing the fires. The persistence of high risk situations will provide more opportunities for intentional fires. We cannot rule out the possibility of these people being encouraged by an occasional fire during these situations. With regard to accidental fires, that is, those whose ignition sources is the result of fortuitous human behaviour, the higher climate-related danger could raise the chances of ignition sources ending in fire. To counteract this possibility, there might be a gradual improvement in information and training for the population, as well as greater awareness of the fire problem, and ignition sources can thus be reduced.

12.C.3.4. Future fire regime and factors that could affect this.

Scenarios of the occurrence of forest fires are characterised by a generalised increase in the danger rating indices, longer duration of the fire season and greater frequency of extreme, longer-lasting situations. To this is added the tendency towards a change in vegetation, with greater abundance of shrub species, which are more sensitive to water stress. Consequently, fires can be expected to be more frequent, widespread and intense. These tendencies will vary from one area to another, but will accentuate current tendencies.

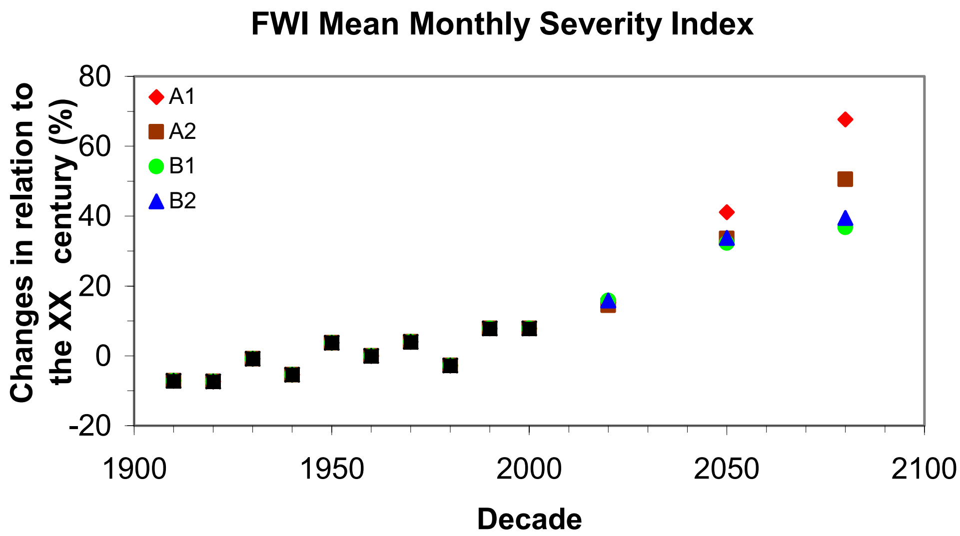

Fig. 12.C.9. *Variation (%) in the FWI mean monthly fire danger index (Canadian Fire Danger Rating System) for Mainland Spain and per decades (the datum refers to the last year thereof) in relation to the average of the XX century for two centuries. The data for the XX century were reconstructed using the ERA base and the one by New et al. (2002), adjusted with real seasonal data. The data for the XXI century are from the predictions by the HadCM3 model, from the Hadley Centre in the United Kingdom, for four emission scenarios, and rescaling according to New et al. 2002. The values of each year are calculated based on the monsths of May through October, inclusive. (Moreno et al. 2005).*

The negative projection of the occurrence of fires with climate change can be counteracted through improvements in weather forecasting, knowledge of the state of fuels, as well as surveillance and prevention strategies. Current weather forecasting enables us to establish, a few days in advance, the possible existence of danger situations. With the passing of time, improvements in forecasting systems will probably enable us to cover longer meteorological periods. Improved capacity to forecast danger could enable resources to be better planned, and, in particular, could help to implement prevention actions in the areas with highest risk levels. In this sense, the drafting of prevention plans for estates and the compulsory registering of burnt areas and associated restoration plans, such as are implemented in some Regional

Autonomies, could help to make all those involved more aware. In this sense, better knowledge of fuels could be of help, in relation either to the quantity and spatial distribution of these, or to their state of hydration and phenology (González-Alonso *et al*. 1997; Chuvieco *et al*. 2003; Riaño *et al*. 2003; Gonzalez-Alonso *et al*. 2004). Likewise, important improvements are expected as a result of the implementation of fire danger systems based on the real conditions in each area, with increasingly smaller resolutions (Carlson *et al*. 2002). This, together with improvements in the surveillance systems will enable us not only to reduce response times, but also to adjust these to the real degree of danger involved in the outbreak of a fire.

In order for the systems to be more effective, a change in fire fighting policies is needed. A policy based strictly on the exclusion of fire could be counterproductive, especially when changes are to be expected in the forest potential of many areas, and the tendency to dominate of shrubland systems becomes more widespread. This will apply more pressure to the forested areas, and defensive strategies based on these areas will therefore need to be articulated. In this sense, there is a critical need for management guidelines aimed at reducing the amount of fuel in areas with greater potential for a large-scale fire. These management guidelines should consider the use of fire as one more of many available tools. This type of strategy may not eliminate the occurrence of certain types of fires, but it only allows these to propagate out of control in extreme conditions.

The expected result is that improved prevention, danger assessment and surveillance will allow many forest fires to be contained before they reach a certain size. Eventually, only the ones occurring in very dangerous circumstances will finally prosper. Consequently, the distribution of sizes could therefore be expected to become more unequal. The recurrence of extreme situations is a clear possibility, and in these circumstances, fire fighting systems are less efficient. The tendency towards a very unequal distribution of fire sizes will therefore become consolidated, along with annual variability. With regard to the causes of fires, greater awareness and education of the population will help to reduce the fires caused by negligence, although the ones caused by lightening will persist and become bigger. Their higher concentration at certain sites and improved forecast means that these type of fires will only be able to occur in extreme situations. The incidence of deliberate fires is impossible to predict.

In short, the higher danger level may be partially counteracted by increased awareness and education. More efficient surveillance and prevention could mean that many focuses of fire are brought under control. However, we can expect those fires occurring in more adverse conditions, which will be more frequent, to prosper, both those caused by man and by lightening. Given that the area affected by a small number of fires determines the total annual burnt area, the latter can be expected to increase, in spite of the fact that few fires escape control by the fire fighting system, and that this area becomes more variable year after year. The maximum size of a fire will tend to increase throughout the whole country, and large fires may occur in places theretofore unaffected. The scenario of large fires appears to be highly likely.

12.C.4. MOST VULNERABLE AREAS

Vázquez *et al*. (2002) showed that, during the 1974-94 period, the proportion in number of big fires (>500ha) was related to high temperatures and a large number of days that had elapsed since the last rainfall. On the other hand, a high spatial and temporal frequency of fires was correlated to high relative humidity. The area affected by medium or large-sized fires, or the seasonal variability of these, was positively related to high temperatures and to the number of days that had elapsed since the last period of rainfall. To the contrary, as with the number of fires, a high proportion of areas (10000 ha squares) with high area burned (>500 ha) was correlated with high relative humidity values. These differences are a good reflection of what occurs on the gradient running from Mediterranean Spain to Atlantic Spain, particularly from the South and East to the North and Northwest of the Peninsula. In the Northwest, fires are relatively small, generalized in the country and occur under milder conditions, as they are caused by humans. In the Mediterranean, this are less frequent, but larger and occur under more extreme conditions.

Under the expected changes, the frequency of high temperatures and number of rainless days will increase, and, as the century elapses, will spread to the whole peninsula, and will become more lasting. On the other hand, it has been observed a positive relationship between the rainfall in one year and the surface burned during the next one (Pausas 2004), which indicates that the global effect of years particularly wet may not be positive. Consequently, we could expect the impact of a more extreme fire regime, subsequent to the new climatology, would be proportionally less relevant in those parts of Spain in which this pattern can already be seen, as it happens in most Mediterranean areas. Because arid areas already experience prolonged drought, it is unlikely that further increases in drought will comparatively have a large impact on fire frequency or size. To the contrary, in the areas in which the pattern of fire occurrence is very different to the one anticipated, as it happens in the peninsular North and Northwest, we could expect the capacity to withstand a new fire regime will to be lower. This is, in areas where prolonged droughts are now rare are most likely to be more sensitive to changes in fire regime. Furthermore, the high spatial distribution of fires in this part of our geography, together with the high degree of deliberateness of these, indicates that these areas are the ones with the highest levels of vulnerability. The above mentioned study demonstrates the existence of a relationship between the proportion of area burned by large fires and the proportion of fires caused by negligence or lightning. In this sense, a change in the pattern of ignition sources in the direction of becoming dominted by fires caused intentionally or by unknown causes to another dominated by fires caused by negligences could conduce to a fire regime that is typical in most Mediterranean Spain, in view of what has been observed in the two decades analysed. The greater abundance of forest in the North and Northwest of Spain permits to conjecture that fire frequency will remain high. The high primary productivity of these areas (Rodríguez Murillo 1997), and the high-stress situations they could be subjected to in the future (see Chapter 9), suggest an increase in the areas in states of regeneration following fire, resulting in greater danger. The most productive areas are the ones with the highest probability of undergoing a change in fire regime in comparison with the present one.

The vulnerable areas are also those in which fires have been relatively infrequent and which, in biogeographic terms, are areas the potential vegetation of which comprises beech forests, high plateau regions with *Juniperus* or high mountain pine and fir forests (*Pinus uncinata*, *Abies*). The increased danger, in some cases (high mountain) combined with the greater pressure upon forest areas, particularly in summer, could lead to fires of unknown frequencies or magnitudes. The lower resilience of these ecosystems to fire could hinder their regeneration after fires, with the consequent danger for the existing vegetation and a change therein. Because of their large area and importance, high plateau areas could be some of the most vulnerable ones.

Finally, the rest of Spain, which is already dominated by fire regime made up of medium to large size fires, with fires more related to negligence or lightning, and defined by high temperatures and long time periods since the last fire, will see this tendency incremented. Once again, the greater or lesser inclination of these areas to develop continuous vegetation in a short period of time, which will vary from one area to another depending on the degree to which productivity is limited by temperature, can cause the spread of these situations, the present pattern becoming more evident. The tendency towards more widespread and intense fires will therefore increase, as will frequency, due to the higher probability of a fire being caused through negligence.

12.C.5. MAIN ADAPTIVE OPTIONS

12.C.5.1. Fire fighting and prevention strategies

The option of fighting all fires in an environment of danger and increasing risk might simply be technically impossible and economically unfeasible. Furthermore, from the ecosystem management point of view, some of these could be managed taking fire into consideration, that is to say, by periodically incorporating fire into management schemes. In this sense, it appears to be necessary to determine where and when a fire is unacceptable at any cost and where or when it can be tolerated or even desirable, albeit in order to minimise the risk of an uncontrolled fire. This can be dome by implementing forest management systems that contemplate the use of prescribed burning (Rodríguez Silva 1998 2004). This is done at present, but will be even more necessary in the future. The concept is that fire can be used to control the types and amounts of fuels. It is generally true (but with noteworthy exceptions) that an area that is burned is highly unlikely to burn for some years. This offers the possibility of using management burns to create zones through which fires will not spread. This is suggested, for example, as a means of protecting areas of economic value and that are sensitive to fire from wildfire, such as young tree planatations, or buildings adjacent to wild areas, etc.. But fire management is not without risks. Anytime fire is set, there is some probability of escapte outside the designated boundaries. Therefore, its use must be made cautiously.

Given the large amount of resources used in combating and preventing fire, and the limited effectiveness that can be expected, in view of the results of cost-benefit analyses (which means to say, investing more resources does not necessarily lead to greater effectiveness (Martell 2001)), there appears to be a need to revise fire fighting policies, fundamentally through changes in prevention strategies, because technical advances in the capacity to fight fire once this has started and been detected seem to be limited. In this sense, fuel management techniques (whether these involve clearing, prescribed burning, the use of herbivores or others) should advance through knowledge of plant species and ecosystems, in order to allow for the integrated management thereof, and should contemplate, apart from fire prevention, the conservation of biodiversity, carbon fixation and the fight against desertification.

Table 12.C.1. *Summary of the main impacts of climate change on fire regime and occurrence in Spain (Scale of 1 to 5).*

Variables related to the occurrence of fires	Change	Certainty
Danger of fire	Increase	*****
Frequency of fires	Increase	****
Maximum size of fires	Increase	*****
Intensity	Increase	*****
Danger zones	Increase	*****
Fire season	Increase	*****
Annual variability	Increase	*****
Fires caused through negligence	Increase	****
Deliberate fires	Increase	**
Fires caused by lightening	Increase	****

12.C.5.2. Silviculture and land uses

Past studies show that, although in the country as a whole, the type of plant cover does not seem to be determinant in the occurrence of fires (Vázquez *et al*. 2002), in certain areas, the fires have been selective, which means to say, they did not affect all the vegetation in the same way (Viedma and Moreno, submitted). Furthermore, it is not easy to make predictions in relation to the commercial values of forest plantations in the near future. If we consider, however, that in the past a considerable amount of plantations were burnt down at early ages (Moreno *et al*. 1998), then we can expect the same to occur in the future. The occurrence of fires in forests with undeveloped soils, which predominate in Mediterranean forests and wildlands, could imply a highly negative impact on edaphic resources, due to the loss of nutrients and soils involved (Soto and Díaz-Fierros 1998; Bautista *et al*. 1996; Andreu *et al*. 1996). The scenario involving rain concentrated in time suggests that the negative effects will tend to increase (De Luis *et al*. 2003). The greater frequency of droughts might be doubly negative, as this limits the development of the vegetation in early stages. Consequently, forest management strategies in the different territories of Spain, including reforestation species, in particular those with a high forest potentiality, should consider the possibility of frequent fires (Pausas *et al*. 2004). The risk associated with soil loss should be calculated in order to verify the suitability of the different land uses.

12.C.5.3. Recreational uses of forest and wildlands

The tendency towards population increase, socioeconomic improvements and the growing interest in remaining in contact with nature suggests that the demand for use of forests and wildlands will increase. Improved education will probably lead to greater sensitivity to risk and less dangerous practices. More intense recreational use of forests and wildlands, however, together with longer periods of activity due to the milder temperatures, could give rise to serious risk factors, although it is impossible to quantify this. We should also consider fire risk in town planning, so that any reclassification of lands for development will take fire into consideration. Furthermore, legislation ought to be reinforced in relation to fire protection in the urban-forest interphase, and measurements designed to implement this.

12.C.5.4. Surveillance and warning systems

Improvements in the surveillance systems, favoured by technological development, will facilitate widespread application, shortening detection and response times, which will constitute a great backup for the fire fighting systems. Furthermore, the possibility of availing of fuel maps with high spatial resolutions, showing the condition of the fuel (moisture content) and adjusted to meteorology, together with the integration in SIG of all the existing information and with the application of fire spread models in the event of an incipient fire, will facilitate rapid and opportune response. Likewise, the availability of *in situ* information provided by remote communication systems and computerisation, will constitute powerful tools for the forest manager for better gauging the imminent danger and improving fire fighting. The capacity for medium-term prediction, with approximate simulations of the worst possible conditions, can allow for better campaign planning. All of this suggests that the capacity to fight fire is increasing, especially in the early stages of a fire.

12.C.6. IMPLICATIONS FOR OTHER SECTORS OR AREAS

12.C.6.1. Forestry sector

Timber and fibre production may be altered by climate change and by increased fire danger. Variations in climate will mean that currently productive areas will cease to be so, and vice versa. These changes will be too rapid and unstable, however, to take advantage of them and to plant forest plantations, given their cycles, which can last up to tens of years. The possibility of forest fires will have to be included as a negative element when dealing with these actions. It is also likely that a growing number of forest plantations will be affected by fire before reaching commercial value. This could reduce the sector's production capacity.

The increased risk of fire predicted is a factor that must be included in any forest management plan. Furthermore, the scenarios upon which some of the present plans have been based, in relation to situations of risk, may become worse. This means that the barriers designed to stop fires, along with the associated fire fighting techniques, may not be as effective as was originally thought. Consequently, forest management plans ought to contemplate a range of future scenarios, including the worst ones, within the temporal framework for which determined planning is designed. This planning ought to take into account the vegetation dynamics resulting from fire, along with the associated risks, under scenarios of increasing danger. In prevention actions, the dimension of the defence elements should be considered in view of the increasing linear intensities of the fire fronts. Given the current and growing importance of CO_2 emissions into the atmosphere, and the role that fires can play in relation to the capacity of forest systems to act as carbon sinks (Rodríguez Murillo 1997), there appears to be a need to predict the feasibility and shortcomings of fire management plans from this perspective, especially with regard to those that could be included within the framework of emissions and sinks of the Kyoto Protocol, and in future agreements.

12.C.6.2. Soil conservation

Frequent drought scenarios, rain concentrated in time and increased fire danger make soil conservation of vital importance, considering that, soil fertility permitting, vegetation can be expected to develop in few years, becoming very dangerous and increasing the occurrence of fires. Consequently, in areas with greater danger of erosion, reforestation plans should be a priority, because in the event of a fire, these allow for sufficient recovery of plant cover to reduce risk. Considering that certain forest species negatively affect some resprouting species (Bellot *et al*. 2004), there is a need for techniques that allow for the presence of these species so that, following a fire, they can produce minimum plant cover (Vallejo and Alloza 1998; Maestre *et al*. 2001) thus increasing resistance to fire.

12.C.6.3. Recreational use

The capacity of forests and wildlands to accommodate visitors, and therefore for recreational use, could be affected. Increased risk of fire and the spread of this throughout the year could lead to restrictions in the use of forests and wildlands aimed at avoiding greater danger, as is already being implemented in some parts of Spain. This, together with the greater demand for available open spaces, could give rise to conflicts, which will need to be solved with the use of appropriate information and education. The areas with the biggest influxes of visitors will require more active and permanent surveillance.

12.C.6.4. Plant and animal biodiversity

A possible increase in the occurrence of fires could lead to the dominance of pioneer vegetation, consequently reducing plant diversity. More frequent droughts, before and after fire, could bring about more widespread and intense fires, hindering the colonisation of species, either because it is more difficult for seeds to be transported from outside the fire zone (Rodrigo *et al*. 2004), or because it is impossible for the species to become established in the temporal window that limits some of these (Quintana *et al*. 2003), which can lead to local extinction. The homogenization of areas recurrently burned will decrease animal biodiversity and can alter the interactions among species (Moreira *et al*. 2001; Torre and Díaz 2004). Fires can therefore cause habitat and species loss. In this sense, the vulnerability of protected terrestrial areas should be considered in view of the growing danger of fire.

12.C.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

12.C.7.1. Relationship between risk and occurrence of fires

As the vast majority of fires are deliberate, the main uncertainty is related to how future conditions can affect human behaviour patterns in relation to causing more or less fires. We could expect people to become more aware of risk, in view of recurring devastating fires, caused by negligence or by high-risk situations, with the consequent reduction of the causes of fire through negligence.

12.C.7.2. Changes in the landscape and occurrence of fires

One of the foundations of fire fighting involves the importance of landscape structure in determining the spread of fire (Minnich 1983; Green *et al*. 1990). Consequently, in some countries, actions have been implemented aimed at favouring the diversity of the landscape mosaic. However, in the environments dominated by crown fires, whether these be in shrublands or in forests with complex structures, it seems that landscape structure plays a less important role, with regard to stopping fire, in extreme conditions (Johnson *et al*. 2001; Keeley and Fotheringham 2001). Although we know that spatial heterogeneity at the very least helps in management and extinction work, it is undoubtedly one of the most unknown elements in forest planning. Until we have made a better appraisal of how landscape structure conditions the spread of fires in different risk situations, the land planning applied or any real assessment of danger in a given area will continue to be uncertain.

12.C.7.3. Interactions with other impacts

There is a clear possibility that prolonged droughts will affect vast areas, thus causing the generalised or selective death of certain species and brusquely influencing the danger status of a territory (Peñuelas *et al*. 2001). There will also be interactions with certain pathogenic agents which will cause the death of their hosts (Hodar *et al*. 2003), thus increasing dead biomass. This will influence the hazardousness of the system for a long time, due to the deposit of dead material which can remain standing, without decomposing, for years.

12.C.7.4. Changes in the use patterns of forests and wildlands

It is likely that changes in the use patterns of forests and wildlands will constitute one of the most relevant alterations to be expected. On the one hand, due to the greater demand for recreation; on the other, because of increased residential use. We can only expect an increase in the dangers posed by these uses with regard to ignition sources or to the damage that could be caused in the event of a fire. The tendency towards residential use of forests and wildlands or of forest habitats, which is already occurring in many places (the coast, the vicinity of big towns), involves pressure with the associated and growing risk which is difficult to quantify.

12.C.8. DETECTING THE CHANGE

Detection of change in the occurrence of forest fires in Spain is difficult because of the lack of historic data covering the XX century, with the exception of the final part. Fortunately, the EGIF database of the General Direction for Biodiversity (MIMAM) is sufficiently complete to appraise possible tendencies. Analysis of this type is hindered by the fact that, parallel to the collection of data, there have been socioeconomic, demographic and landscape changes, while forest management policies have been modified and a high level of fire fighting capacity has been reached. Consequently, the climate factor is one more of those affecting the phenomenon of fires, but it is not the only one.

Given the close relationship between fire danger rating indices and the climatic variables determining these (temperature, humidity, rainfall and wind), we can expect the changes detected to have influenced the fire danger rating indices, as available data appear to indicate (Fig. 12.C.9). The identification of possible tendencies in the occurrence of fires is even more complicated if we consider the huge annual fluctuations (Fig. 12.C.1). The instability of the landscapes and of the fire fighting or prevention policies hinders the availability of reliable indices for the detection of change. Among the possible indices parameters could be considered which are based on the distribution of sizes (Vázquez and Moreno 1995; Duguy 2003), either for the whole of Spain, or, preferably, for ecologically similar zones. Other possible indicators could be those related to the effective duration of the fire season, or to the temporal variability in the occurrence of the fires, based on use of accidental ones. An increase in danger level could be expected to cause the earlier appearance of more regular fires.

The biggest problem with regard to determining possible changes in the occurrence of fires is the lack of capacity to predict the number of ignitions, their temporal and spatial distribution and thus their propagation potencial to develop a fire. Unlike fires caused by man, the characteristics of those started by lightening can be established with certain accuracy. Consequently, it would be possible to appraise tendencies in the occurrence of fires by considering the number of discharges and the magnitude, type and location of these.

12.C.9. IMPLICATIONS FOR POLICIES

12.C.9.1. Fire fighting

Climate change and the possible effects of this on fire danger will inevitably affect fire fighting and prevention policies. These policies should focus on managing complex systems, such as forests, that is to say, ecosystems in which fire will be unavoidable when all is said and done. We must therefore decide how these ecosystems are managed and what role, if any, is to be given to fire. Thus, consideration should be given to whether fire is excluded at any cost, or whether it can be accepted under certain circumstances. And, if this were to be the case, where and when will be acceptable that a fire may be the result of clearly established management objectives. In some cases the decision will involve extinguishing the fire, and in others, when the values at stake are not very high, or less important than the resources needed to stop the fire, or if the greater danger is minimised, the fire may be tolerated. It may even be necessary to consider introducing fire under controlled conditions. There is no single recipe for all forest ecosystems in Spain, or for all the situations that can arise. A flexible management system should therefore be implemented, with clear objectives aimed at protecting all the values at stake, firstly people's property and lives, but also the ecological sustainability of the system. In scenarios of greater danger, the policy involving the total elimination of the fire may simply be unfeasible, or undesirable due to the amount of resources required to attain certain levels of efficiency which, in the end, will never quite reach the objectives established (Piñol *et al.* 2004). Climate change should therefore evoke debate on fire fighting and prevention policies.

12.C.9.2. Conservation of biodiversity

At present, conservation policies rarely include fire as an element of the management of protected areas. Besides, no models have been applied to the ecosystems protected, aimed at predicting the impact of a fire. Neither are there any predictions of the impact of conservation management itself, and even less so in relation to how climate change will interact with fire. Consequently, there is a need for models adjusted to the ecosystems subjected to protection, that consider the eventuality not of a fire in itself, but rather of risk situations that increase the frequency, intensity or magnitude of fires. There is a pressing need for appraisal of the vulnerability to fire of the ecosystems and of the protected species.

12.C.9.3. Combating desertification

Part of Spain’s territory, particularly the East of the Peninsula, is affected by desertification processes (Puigdefábregas and Mendizábal 1998). Furthermore, forest fires are a recognised cause of desertification. The fight against desertification, especially in areas with less plant cover, now involves a difficult choice. On one hand, a lack of vegetation cover causes soil loss, and on the other, abundant plant cover increases the risk of fire. With regard to this dilemma, the worst possible scenario is one of frequent fires, because the transitory elimination of plant cover can cause increasing loss of soil and nutrients. In scenarios of increased danger, it is therefore necessary to develop models that simulate the processes involved and serve as guidelines for the management of these territories.

12.C.9.4. Land planning in areas subjected to fire risk

Increased afluence in the last few decades, along with the new tendency to develop part of the forest and wildlands for residential use, have given rise to a new situation in our environment. This tendency can be expected to grow, especially in those areas where there is limited land available for development, such as the coast and residential areas in the mountains. Increased risk of fire in the future can seriously endanger residential areas which were previously safer. Planning of these areas should therefore take into account fire danger and the possible scenarios of climate change.

12.C.10. MAIN RESEARCH NEEDS

There is a need to refine our knowledge of the synoptic conditions that correlate with high fire danger. This requires study of long-term meteorlogical records. With such refined knowledge it will be possible to place fire suppression teams on alert in advance of probable fire incidents

Monitoring data that track the amount, nature, and condition of fuels is needed for all areas susceptible to wildfire. These data need to be translated into a format that allows fire suppression teams and land managers to assess the times and places where fires pose the greatest risks. There must be annual updating to record areas burned. We need to evaluate what is burnt, where this occurs and with what frequency, to evaluate the risk of recurring fires, in order to maintain the integrity of the ecosystem. The risks of “worst scenario possible” type situations should be quantified in order to get a better idea of the budding risk.

The projections by the GCMs are not spatially or temporally precise enough to be of practical use in fire management and suppression. Progress must therefore be made in projections by the GCMs at the required spatial and temporal scale. There is also a need for socioeconomic scenarios adapted to the reality of Spain.

We need to understand fire in a landscape context . We must improve our understanding of how management actions affect the fire susceptibility of landscapes. Careful thought must be given to the need to protect certain landscape elements. Advances need to be made in relation to knowledge of the interaction between fires and landscape, as this is the basis of forest planning. There ought to be studies aimed at verifying to what degree risk conditions make the landscape more or less relevant in relation to fire. Research and development of techniques for the management of ecosystems threatened by fire should progress and be based on multifunctional management of our forests and wildlands, in order to respond to multiple threats and objectives.

There is still a need for study of the impact of forest fires on the capacity of ecosystems to fix or release Carbon. Direct measurements of C flows in different ecosystems are needed, and of the factors controlling these and their interaction with fire.

Adverse climatology, specifically drought, not only increases danger, it also can have other adverse effects. For example, the soil moisture levels will affect germinatioin and establishment and by determining the level of plant hydration, may control the capacity of plants to resprout after fire or other disturbances (Cruz *et al*. 2002; Quintana *et al*. 2004). More detailed knowledge is needed of how response by plants varies in extreme situations, particularly in drought. Given that the temporal window for the establishment of certain species is limited, periods of no rain may be more relevant that how much it rains, if there is no rainfall at the right time. Experimental simulations in different ecosystems could indicate what is to be expected in the eventuality of extreme droughts.

Assessment of the state of fuels, of their biomass and moisture, in relation to climate, and at temporal and spatial scales of detail, is vital in the prediction of situations of maximum danger in time and in space.

Further work must be done on the social aspects of fire. Because the actions of humans are so important in all aspects of fire, it is necessary to understand to what degree changes public attitudes and private actions can ameliorate or exacerbate changes in the fire regime due to climate change.

Finally, scenarios of climate change and danger and impact of fires need to be applied in protected areas, in order to assess the vulnerability of these to the growing risk of fires.

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13. IMPACTS ON THE ENERGY SECTOR

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ABSTRACT

Practically all the economic sectors of the country depend on the energy sector, and it should therefore be considered as a strategic one.

Spain depends greatly on international energy, that is oil and its derivatives and on natural gas, and not so much on hydroelectricity and other forms of renewable energy; furthermore, Spain traditionally has had one of the lowest levels of primary energy intensity in comparison with Europe, and also has lower energy consumption per capita.

In recent years, the greatest increases in demand for electric energy have occurred in the South, the Mediterranean Coast and the Centre, and this tendency is expected to continue in the coming years.

The energy sector is one of the culprits of climate change, but is also affected by it. It has been detected that consumption of natural gas (in winter) and electricity (all year round) fundamentally depend on air temperature; thus, warmer winters would cause lower levels of consumption of both, whereas hotter summers would lead to increases in demand for electricity; a growing tendency in the average demand for electricity has been observed in relation to positive (negative) variations of one degree centigrade in summer (winter).

The foreseeable reduction of rainfall will affect the structure of the offer of hydroelectricity, as well as certain thermal power plants and nuclear power plants with broken circuit cooling.
The cogeneration of aeolic energy and the combined cycles used by natural gas (which is a cleaner source of energy) are, to a certain extent, an alternative. The other sources of renewable energy are still at the initial stages of development.

In recent years, many proposals have been presented by the Administration for the promotion both of renewable energy and of an increase in energy efficiency, such as the Promotion Plan for Renewable Energy Sources, and the Spanish Strategy for Energy Saving and Efficiency; measures have also been detected in the financial markets aimed at mitigating the effects of climatic variations on the different economic sectors.

We present different indicators for the detection of climate change in relation to the energy sector; among these, we should highlight the consumption of total energy and total energy intensity, as well as those specifically referring to electricity, particularly domestic and industrial consumption for both refrigeration and heating. Certain modifications are needed, however, with regard to the information provided by the companies, along with an in-depth analysis of the factors intervening in the evolution of the indicators and the specific repercussions of climate change in each sector of economic activity.

13.1. INTRODUCTION

The energy sector, understood as the sector dedicated to transforming and distributing energy, is possibly one of the key parts of the economic machine, as practically all the other ones depend on it. It is also to blame for one third of all emissions of greenhouse gasses. Indeed, according to EEA (2003), in 2001 the energy transformation sector was responsible for 33% of CO_2 emissions, whereas transport represented 25%, and the use of fossil fuels as primary energy for the industry caused 17% of the emissions. It also has a certain technical flexibility to deal with these emissions, by changing the generation *mix.* This chapter does not deal with the causes of the emissions by this sector, but rather, the effects of possible climate change therein, both in relation to the sources of primary energy it uses, and to the processes of transformation of these into total energy (demanded by society, in the form of electricity, of oil products, natural gas and coal).

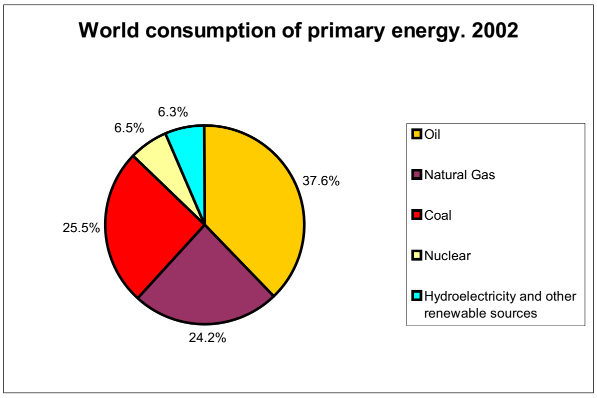
Energy consumption is growing on a worldwide scale and will continue to grow in the near future. This is also occurring in Spain, at an even faster rate than in neighbouring countries. Furthermore, Spanish energy growth rates are above the growth rates of its Gross Domestic Product, which initially seems to indicate that our efficiency with regard to the energy used to generate a unit of wealth is decreasing. Although this is true, certain aspects need to be explained.

On one hand, Spain country has historically had one of the lowest levels of primary energy intensity (relationship between primary energy consumption and Gross Domestic Product) in comparison to Europe, although in recent years it has reached European levels, with regard to equal purchasing power. We also have lower energy consumption per capita.

On the other hand, there has been a decrease in energy intensity in industry, resulting from the better technology adopted and from the move to less intensive activities in the housing, trade and transport sectors, where there have been very high growth rates. The good health of the economy has led to an increase in employment and in income, which has made better facilities possible, as well as levels of consumption closer to European ones, both at the domestic level and in the Tertiary sector. However, the transport sector has shown spectacular growth rates, like in the rest of Europe, but even more accentuated, which has brought about one of the highest levels of energy intensity in transport, resulting from the greater use of road transport in relation to the railway, and over longer distances. This tendency has also been observed in relation to electric energy, due to its characteristics of versatility, availability and price. In recent years, the greatest increases in demand for electricity in Spain have been in the South, the Mediterranean Coast and the Centre, and this tendency is expected to continue in the coming years.

Oil is the main source of primary energy in Spain, as it satisfies approximately 53% of the country's energy needs. Coal and natural gas are the other two most used sources, representing 17% and 14%, respectively, of total energy demand, with opposing evolution tendencies. However, it must be noted that the year 2002 was particularly dry and this affected negatively to hydraulicity. Apart from the inconvenience of depending mainly on one source of energy (oil), there is also the problem that Spain is an oil importer, given that national production only covers 0.4% of the country’s need for crude oil. This high degree of external dependence calls for the implementation of an energy policy fundamentally based on guaranteeing supply.

Figure 13.1 shows the relative importance, both at international and national levels, of energy consumption, depending on the source.



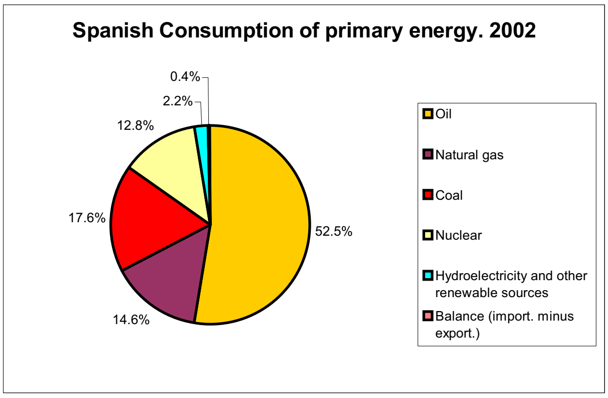


Fig. 13.1. *Sourcess: British Petroleum (2004); DGPEM (2003)*

Furthermore, with regard to the relative importance of each energy source in relation to global consumption on a determined date, we must keep in mind what the evolution of consumption of each one has been in relation to the amount consumed on a given date. This enables us to know, depending on supply forecasts, the situation of Spain with regard to future supply problems, as this evolution is linked both to the world reserves of each source along with their geostrategical location and to the self-supply rate. Figure 13.2 shows, without a doubt, how Spain's dependence on oil has increased since the year 1973 (this date has been chosen as a base for all the sources, as it was the origin of the first world energy crisis); there is a noteworthy increase, however, of other sources in the same period, particularly coal, natural gas and nuclear power.

In this report we will be dealing with five main energy sources: electricity (final energy), oil, natural gas, coal and renewable sources for non-electric use (primary energy sources).

Lastly, we must point out that the energy sector is a strategic one in which guaranteed supply is the key part of the system. This is why, in certain activities, the sector is regulated by the State and in which the role of Supervisor exists (National Energy Commission).

13.2. SENSITIVITY TO THE PRESENT CLIMATE

Climate change is generally detected in an increase in mean temperature, accompanied by a downward trend in rainfall and relative air humidity; in fact, it's quite more complex, as Meteo France, for instance, has shown that variations in climate are different in the Norh than in the South of France. Furthermore, extreme atmospheric episodes can occur with greater frequency and intensity. As indicated by Ayala-Carcedo (2004), in Spain a statistically significant downward tendency has been detected with regard to wintertime rainfall in the 1947-2000 series on the Peninsula, and also an upward trend in the frequency and intensity of extreme thermal episodes.

An initial question that must be dealt with when analysing the sensitivity of the energy sector to the present climate is establishing the climatic variables of greatest influence on the energy sector, this being understood as the sector dedicated to the transformation and distribution of energy. According to Lloyd's (1999), a 3ºC temperature increase causes a 10% variation in energy consumption. It must be kept in mind that when we talk of climatic variables, a wide range of magnitudes can be taken into account: temperature (air or ground), hours of insolation, rainfall, wind speed, relative humidity, atmospheric pressure, etc. Once the most influential variables have been detected, we will attempt to analyse possible variations in their evolution, capable of affecting the energy sector in the future.

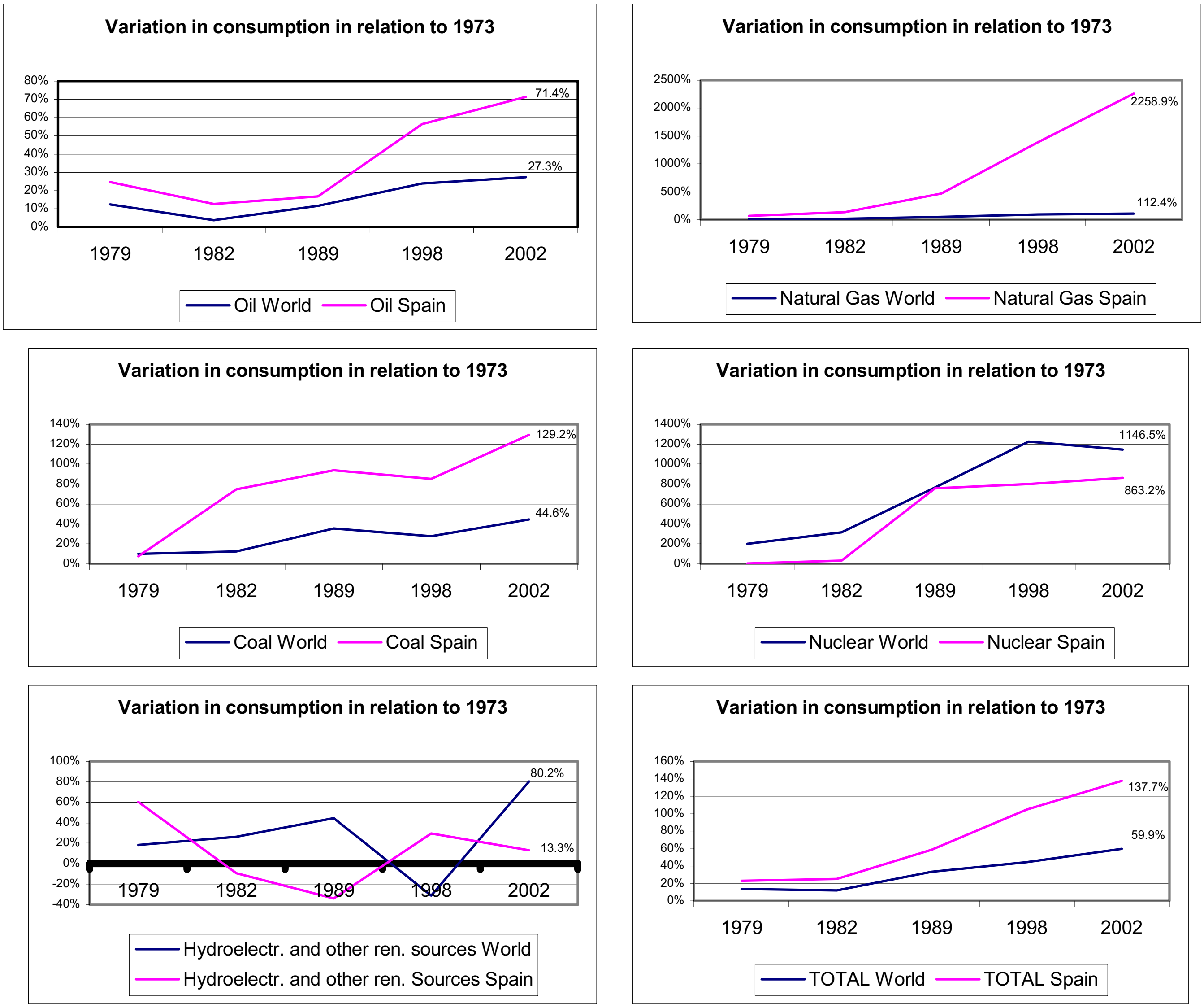


Fig. 13.2. *Source: own design based on British Petroleum (2004) y DGPEM (2003)*

13.2.1. Electricity

13.2.1.1. Demand for electricity

As an initial approach to the relationship between energy and climatic variables, we will take electricity as a representative energy variable. As previously mentioned, electricity is a secondary source of energy. In order to carry out studies, this energy variable has the big advantage of the availability of large databases dealing with consumption levels of very high temporal frequency (daily data, in general, and following the creation of the OMEL market, hourly data on negotiated electric energy). Figure 13.3 shows the scatter graphs relating electricity consumption (only working days) to 6 relevant climatic variables expressed as an index - air temperature ITE, wind speed IVV, relative humidity IHR, atmospheric pressure IP, rainfall IPR and insolation IHS. These indices have been obtained following procedures explained in en Valor *et al*. (2001a y 2001b). The colours blue and red are used to distinguish the days corresponding to summer and winter, as these indicate differentiated types of consumption behaviour.

The most evident factor of climatolgy influencing consumption is temperature. In the first figure of Figure 13.3, there is a convex relationship, so that the data for winter and summer are clearly separated into two sub-sets: the one associated with higher temperatures corresponds to summer (red dots) and the one associated with lower winter temperatures (blue dots). A minimum value appears which separates both sets by approximately 18ºC corresponding to the temperature usually known as comfort temperature (or comfort interval, when a range of temperatures around a mean value is used). The interpretation of this result is that at 18ºC electric energy consumption is minimum, and increases with greater and lesser temperatures due to the activation of air conditioning machines (in summer) and heating (in winter).

The other climatic variables have a lower, practically negligible influence on electricity consumption, as can be seen on the other scatter Figures, and they will therefore not be taken into account in this section of the study. In any case, the combination of some of them could be of certain relevance, for example, temperature and wind speed –*windchill*-, or temperature and relative humidity –*discomfort index*-. It should be observed that in all cases temperature forms part of both combinations, and its role as a climatic variable of maximum influence in electricity consumption is reinforced in this sense.

In order to insist even more upon the relationship between electricity demand and temperature, in the summer of 2003 the heat wave caused big increases in demand for electricity in Spain. Thus, according to the web page of Red Eléctrica de España, electricity consumption in the first twelve days of June surpassed 10.5% of that recorded for the same period in the previous year. The Advance of the 2003 Annual Report by Red Eléctrica de España, relating to the month of August, also showed a 12.6% increase in electricity demand compared with the same month of the previous year; in the same organism's Monthly report for August, it was shown that the mean temperature in this month was 4ºC higher than in August 2002, and that both maximums and minimums were both clearly higher than in the same month of the previous year. Likewise, temperature decreases cause an increase in energy demand; on March 2nd 2004, the energy demand peak in Spain was registered at a value of 38.040 MW at 19:47, and a maximum of mean hourly power of 37.724 MW between 20 and 21 hours. On the same day, the aggregated energy demand was 759 GWh. The previous maximum was registered on February 18th, 2003 between 19 and 20 hours, with a value of 37.212 MW, and the aggregate energy demand of the following day was also the highest in history up to that point in time, with 753 GWh (Red Eléctrica de España. Advance of the Annual Report for 2003); these records coincide with particularly low temperatures in the month of February, 1.5 degrees Celsius lower than the average for the same month in the previous year 2002; specifically, the average minimum temperature on February 18th, was lower than 0ºC, according to the data provided by the Red Eléctrica de España (Monthly Report, February, 2003). Furthermore, on March 2nd 2004, coinciding with low temperatures, the maximum historic demand for natural gas was reached at1.246 GWh.

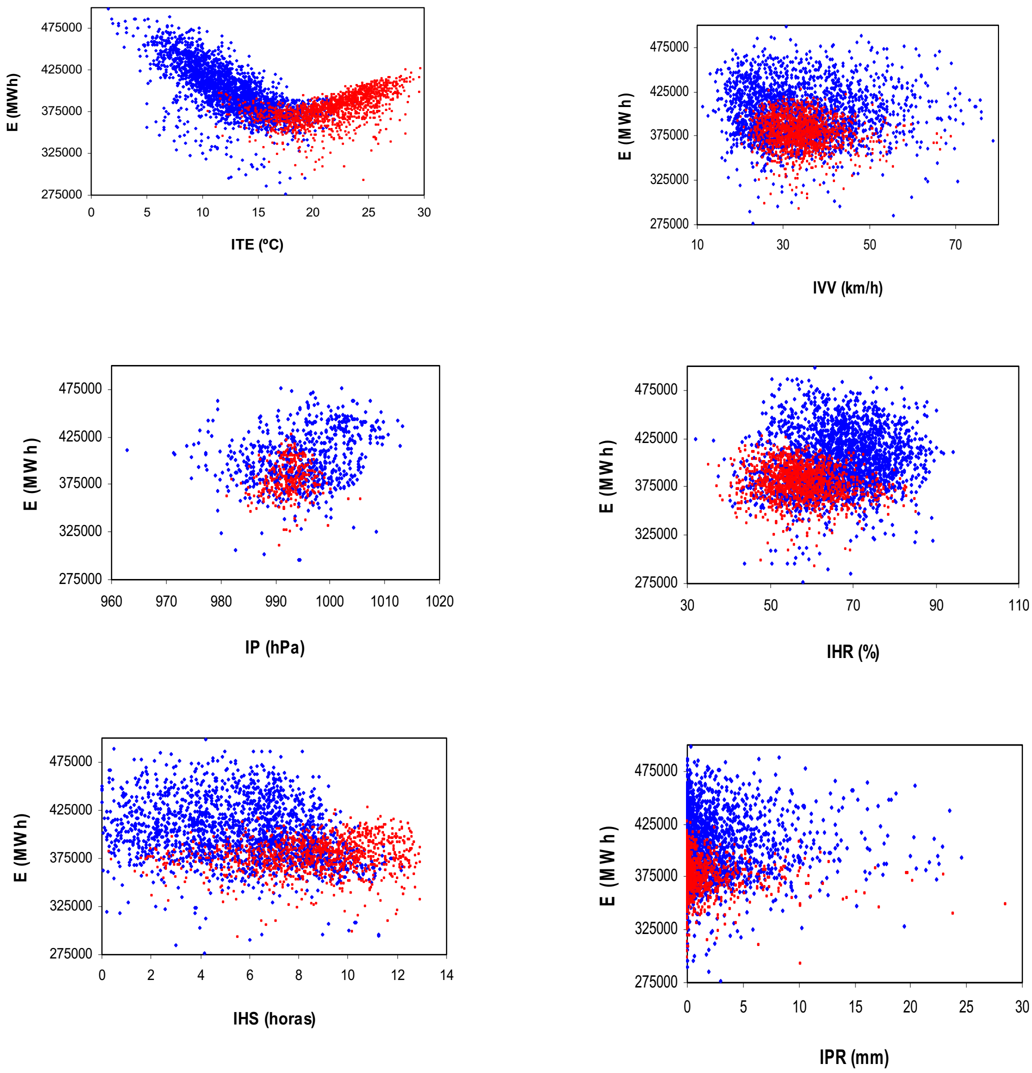


Fig. 13.3. *Scatter graphs of the demand for electricity and climatic variables (temperature ITE, wind speed IVV, Atmospheric pressure IP, relative humidity IHR, hours of insolation IHS, precipitations IPR). Daily data on working days from 1983 to 1999; in the data on electricity demand, the general economic tendency has been eliminated. Source: own design based on data from REE, INM and INE.*

We must insist on this relationship, taking into account the double effect of temperatures on electricity consumption. To this end, we calculated the variables derived from the ITE denominated heating degree days (HDD) and cooling degree days (CDD). Following the methodology described in the literature, the calculation of the degree days was based on:

$$\mathbf{HDD_t = (ITE_{REF} - ITE_t)^+}$$

$$\mathbf{CDD_t = (ITE_t - ITE_{REF})^+}$$

ITE_{REF} being the index value taken as a reference and ITE the index value in t (t= 1,2,3,…). In the case of Spain, the reference value of the index to be used is 18ºC, which is the previously analysed comfort temperature. The interpretation of the heating degree days is the number of degrees for which it would be necessary to use energy resources during the winter days in order to reach the comfort environmental temperature. The cooling degree days would be the degrees necessary, using energy resources, to bring the temperature down to the comfort level. That is to say, they are a measure of the duration and intensity of the cold in winter and of the heat in summer.

Figure 13.5 presents the evolution of the cooling and heating degree days from 1970 to 2003. Each variable represents the annual sum of the degree days obtained, applying day by day, the previous relationships. Simple observation of the Figure provides information on the clear downward tendency of the annual heating degree days, as well as the evident upward trend of the cooling degree days, both of them the consequence of a rise in mean temperature in the last thirty three years.

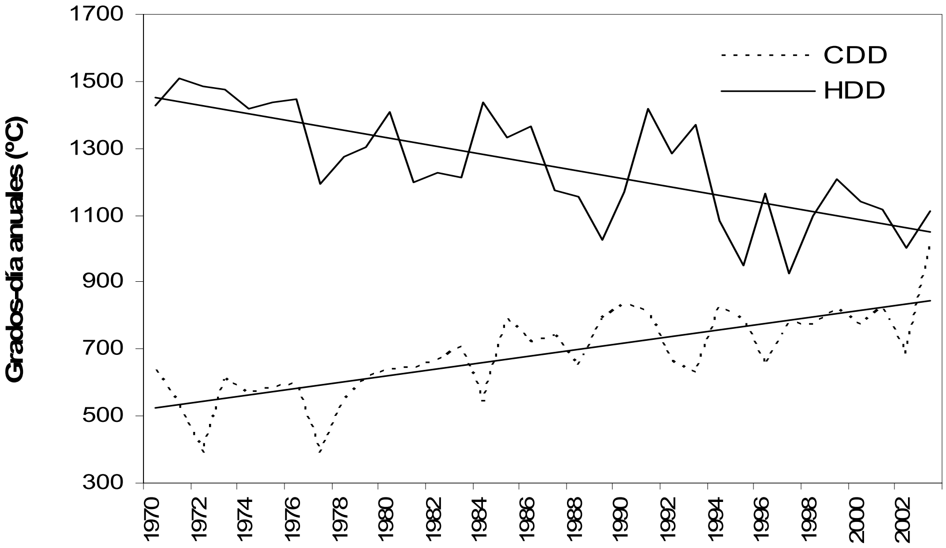


Fig. 13.5. *Evolution of the annual sum of cooling (CDD) and heating (HDD) degree days from 1970 to 2003. Source: own design based on data from the INM*

Once the cooling degree days and heating degree days have been obtained, it is possible to determine in an approximate manner the response of mean daily demand for electricity in summer and in winter to a temperature variation of one degree. Table 13.1 shows the result of this approximation, and this response is detailed for the years 1983, 1993 and 2003. The growing trend in summer is notable.

Table 13.1. *Percentage variation of mean daily electricity demand caused by a variation in temperature of ±1º C. Source: Own design based on data from REE and INM*

Year	Winter	Summer
1983	1,85 %	0,47 %
1993	2,06 %	1,07 %
2003	1,80 %	1,61 %

13.2.1.2. Electricity supply

But it is not only the demand for electricity that is affected by temperature variations. The generation of electricity itself is also sensitive, to a greater or lesser degree, to variations in climate. Thus, directly related to rainfall and to the capacity of the reservoirs, it affects the price of electricity. For instance, the month of August, 2003, was particularly dry, with a hydraulic producible energy 7 GWh below a standard August. This, combined with the heat wave, caused the average electricity price to rise up to 4 cents of a Euro per KWh during this month, 25.3% higher than that of the previous year, and the maximum in the previous thirteen months, according to the Electricity Market Operator, OMEL (information by Reuters, August 29th, 2003). The previous maximum price had been in July, 2002, at the time 4.72 cents of a Euro per KWh, in a particularly dry year.

The hydraulic producible energy shows the maximum amount of electrical energy that could be produced in theory, considering hydrualic production recorded in a given period of time, once the water use has been calculated for irrigation or other uses different from the production of electrical energy; with regard to the producible index, this shows the ratio between producible energy and mean producible energy, both of these referring to the same time period and to one same hydro power equipment. This index therefore correctly shows the temporal hydrological cycle, and a unitary value of this indicates a normal period with regard to hydraulic yield; lower values of the unit, however, reflect dry periods, whereas values higher than the unit reflect humid periods (see their evolution from June, 2002 to June, 2003 in Figure 13.6). It is precisely the year 2002 that presents a producible index of 0.73, according to data from the Red Eléctrica de España (Advance of the 2003 Annual Report), compared to one of 1.16 for 2003, which probably explains the average price of electricity in July of that year. And the same thing happens to electricity prices in August, 2003, with a producible index of 0.56. As we can see, the combination of heat and little hydraulicity has clear effects on prices.

Furthermore, we are also aware of the effects of temperature on the different performance levels of thermal and nuclear power plants, an on the ones dedicated to cogeneration, high-temperature thermal solar energy and on biomass. The Rankine cycle reduces their thermodynamic performance when the cool focus is lower. Besides, the thermal impact is increased, as happened, for example, in France, a country with a huge production of nuclear generated electricity, when the nuclear power plants in Bugey (Ain, east), Golfech (Tarn-et-Garonne, south) and Tricastin (Drome, southeast) received authorisation in August, 2003, to dump into rivers the water used for cooling reactors, at temperatures higher than what is permitted by the regulations in force.

Wind energy is clearly affected by anticyclonic conditions and with extreme instability episodes (very high winds). In the case of photovoltaic and of thermal solar energy, strong winds raise dust (dirtying panels and heliostats), and production has to be stopped. The biggest problem at present for these facilities is heat dissipation. Cell performance decreases with temperature. In the case of those made of single crystal silicon this is a decrease of 4.41% each 10º C, above 25º C. These cells also have maximum functioning temperatures in the range of 70º C, which cannot be exceeded. However, the effect of the hours of insolation is very positive in these technologies.

Furthermore, temperature increases give rise to much milder winters and to much hotter summers (figure 13. 5). Increased demand, combined with this temperature effect, leads to an increase in summertime demand for electricity. This effect can be seen year after year in the approximation of the peak power demand in summer to the values demanded in winter.

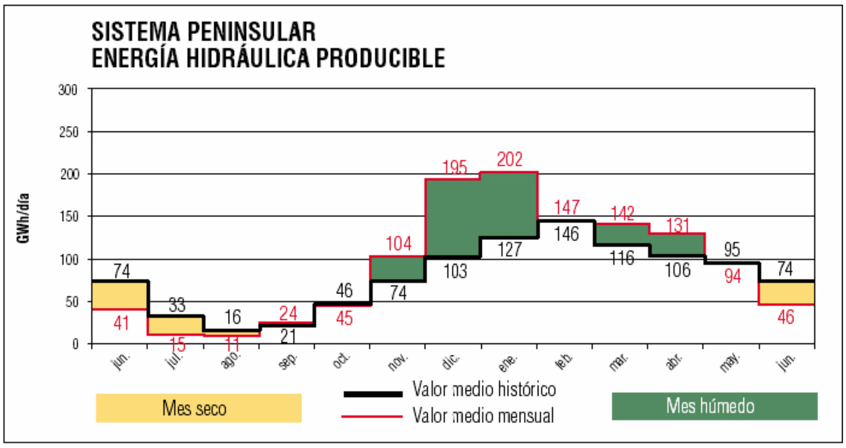


Fig. 13.6. Producible index during the last moving year (June, 2002 – June 2003). (black line: historic mean; red line: mean monthly value; yellow: dry month; green: wet month) Source: REE.

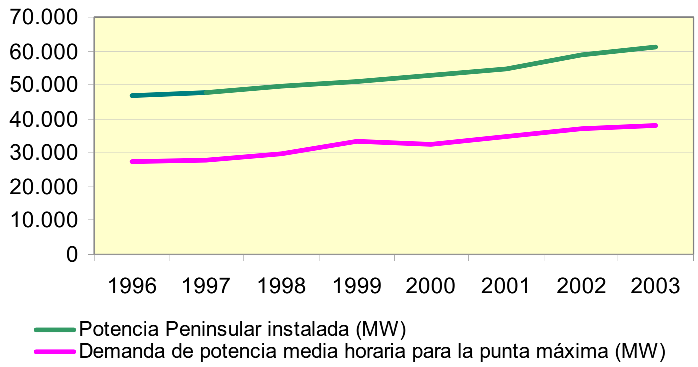


***Fig. 13.7.** Relationship between installed power (green) and power demand (red). Source: REE and own design*

The transport and distribution of electrical energy are also sensitive to climatology. Air temperature affects the transport capacity of high-voltage power lines (see in Table 13.2 the different capacity of international connections in Spain in summer and in winter); wind, torrential rain and snow also have a clear effect with regard to the potential destruction of transport infrastructures. Lastly, the effects of air temperature (isolated, or in combination with relative humidity), the *discomfort index,* or wind speed, *windchill index*) are also important in the distribution of electricity.

13.2.2. Natural gas, oil and coal

13.2.2.1. Demand

Could it be said that the influence of climatic variables on the consumption of other energy sources, fundamentally the primary ones, is similar? Figure 13.8 presents the scatter Figures of dispersal between gas, coal and hydrocarbons and temperature index, ITE (monthly consumption data and mean monthly ITE value). We have reached the conclusion that the consumption of gas is related to variations in the ITE, and that consumption of coal and hydrocarbons is also positively related, but much more diffuse. In any case, compare the behaviour of the relationship obtained with that of electricity. In the case of gas and hydrocarbons, we do not find the ascending branch corresponding to high temperatures (summer), due to the fact that air conditioning systems are not activated with these energy sources. No relationship for coal is detected, either in summer or in winter. It could be considered that the indirect influence of these high temperatures on the consumption of gas, coal and hydrocarbons through the generation of electricity does not appear to be relevant at present.

Table 13.2. *Maximun nominal capacity per interconnecting power lines on December 31st, 2002 (Voltaje, kV; in summer; in winter) Source: REE.*

Capacidad nominal máxima de las interconexiones internacionales (MW)			
	tension (kV)	**En verano**	**En invierno**
Con Francia			
Irún – Errondenia	132	111	133
Arkale – Argia	220	410	460
Hernani – Argia	400	1430	1620
Biescas - Pragnéres	220	270	330
Benos - Lac Dóo	150	100	140
Vic – Baixas	400	1510	1750
Con Andorra			
Adrall – Escalades 1 y 2*	110	60	85
Con Portugal			
Cartelle - Lindoso	400	1040	1330
Conchas – Lindoso 132	132	105	140
Aldeadávila - Bemposta	220	270	340
Aldeadávila - Pocinho	220	270	340
Saucelle - Pocinho	220	270	340
Cedillo - Falagueira	400	790	1410
Santa Marina - Elvas 1 y 2*	66	40	70
Con Marruecos			
Pinar - Melloussa	400	730	730

* Valores por circuito

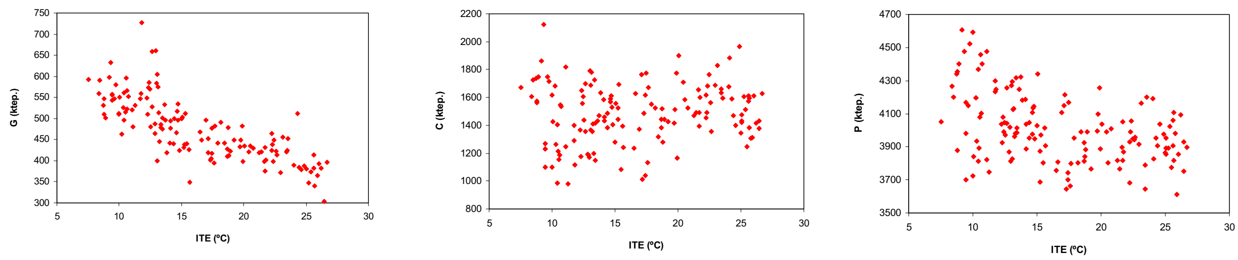


Fig. 13.8. *Scatter Figures of the monthly primary demand for gas (G), coal (C) and hydrocarbons (P) and temperature from 1987 to 1998; the general economic trend has been eliminated from the energy series. Source: own design based on data from de MINER, INM and INE.*

13.2.2.2. Supply

Incidents in the supply of natural gas by sea in methane tankers, clearly depend on the state of the sea. Regasification (a process by which gas is regasified, as it is usually transported in a liquid state) may be favoured by an increase in environmental temperature, just as transport and distribution through open air gas pipelines are favoured. But, in a symmetrical way, liquification at the point of origin will be negatively affected by a temperature increase, and, although this type of facilities do not exist in Spain, this effect, above a certain threshold, could have negative repercussions for the international supply of gas. .

The oil industry is equally sensitive to climate variations. The quality of refinery products, for example, will necessarily vary with air temperature. Distribution and marketing also depend on climatological conditions, fundamentally when oil tankers and trucks are used.

With regard to coal, this depends on climatology in the extraction and preparation, storage and distribution phases, depending on intended uses. The first phase is clearly affected by rainfall, which, when excessively abundant, can cause problems both in quarries and in underground mines. During storage of coal, air temperature can cause spontaneous combustion, with the accompanying risks. Wind speed can cause fugitive emissions, reducing the final amount of mineral available. Likewise, runoff can cause a serious reduction of the amount of mineral stored. Lastly, the marketing of coal will be affected by hydraulicity (dry years will lead to greater use of thermal power plants) and by air temperature, which will obviously cause greater heating demand or less demand in the domestic use of coal for heating.

13.2.3. Non electrical use renewable energy sources

With regard to the sources of renewable energy of non electrical use demand, these also present evident sensitivity to climatology. Low temperature thermal solar energy logically depends on the insolation received, and biomass shows real characteristics and seasonal cycles depending both on the type of soil and water availability. Indeed, climate is a variable that determines the type of crop possible in a determined area. With regard to biocarburants, tropical crops of sugar cane allow for an average production per Ha of 6,000 litres of bioethanol in Brazil, whereas in Europe, as cereals are used, this performance is limited to less than half this amount. Furthermore, in Europe a large amount of biodiesel is produced from rapeseed oil, mainly in Germany and France.

We now indicate how an alteration of meteorological variations affects crops, fundamentally in the case of Spain and in relation to biethanol from cereals, currently the most commonly used biocarburant in the country.

Increase of rainfall: In general very positive, although this should occur in its natural periods.
Increase of hours of insolation: Positive
Increase of relative humidity: Positive
Increase of temperature: Very high or very low ones harmful. Slightly high ones, favourable.

13.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

This epiFigure shows the possible effects of climate change on the energy sector. Obviously, no attempt will be made here to quantify these effects, but we will try to make a qualitative appraisal of them. We attempted to distinguish three levels: positive, negative and neutral. Where necessary, the effects have been distinguished according to the type of energy. Table 13.3 summarised the main results.

13.4. MOST VULNERABLE ZONES

We now provide a series of maps showing the physical distribution of transformer stations (electricity power plants, facilities for the regasification of liquefied natural gas and refineries) as well as their permanent transport networks, based on electricity, oil and gas.

***Table 13.3.** Main impacts of climate change. Source: own design*

		Rainfall		Temperature		Wind		Others
		Increase	Decrease	Increase	Decrease	Increase	Decrease	
Electricity	Generation	Positive (hydraulicity)	Negative	Negative*	Positive*	Positive in aeolic	Negative in aeolic	Solar: insolación positiva
	Transport and Distribution	Negative	Positive	Negative	Positive	Negative if it is very high	Neutral	
	Marketing/demand	Neutral	Neutral	Negative **	Negative **	Neutral	Neutral	Combination Temperature/Humidity and Temperature/Wind: Joint increase causes negative effect
Natural Gas	Supply	Negative	Positive	Neutral	Neutral	Negative (boat)	Neutral	
	Regasification	Neutral	Neutral	Positive	Negative	Neutral	Neutral	
	Transport and distribution	Negative	Positive	Positive (open air oil pipelines)	Negative (open air gas pipelines)	Neutral	Neutral	
	Storage	Neutral	Neutral	Negative (open air storage	Neutral	Neutral	Neutral	
	Marketing/ Demand	Neutral	Neutral	Negative **	Negative **	Neutral	Neutral	Combination Temperature/Humidity and Temperature/Wind: Joint increase causes negative effect
Oil	Refinery	Neutral	Neutral	Negative	Positive	Neutral	Neutral	
	Transport and distribution	Negative	Positive	Negative	Negative	Neutral	Neutral	
	Demand	Neutral	Neutral	Negative **	Negative **	Neutral	Neutral	
Coal	Extraction	Negative	Positive	Negative	Positive	Neutral	Neutral	
	Storage	Negative	Positive	Negative	Positive	Negative	Neutral	
	Demand	Negative	Positive	Negative **	Negative **	Neutral	Neutral	
Renewable – non-electric use	Production	Positive in biomass	Negative in biomass	Negative in biomass	Negative in biomass	Neutral	Neutral	Low intensity solar: positive insolation

* Affects performance of theromoelectric plants, nuclear power plants, cogeneration, biomass, thermal solar energy, etc. Likewise, it is more difficult for photovoltaic solar energy to dissipate heat.
** considered negative on presuming greater demand of the resource
Note: increases or decreases in the climatic parameter considered should be taken as significant.

13.4.1. Electricity

13.4.1.1. Electricity generation

The generation stations generate around 64.000 MW, of which approximately 51.000 MW correspond to the ordinary regime, the rest pertaining to the special regime (see distribution on Figure 13.9).

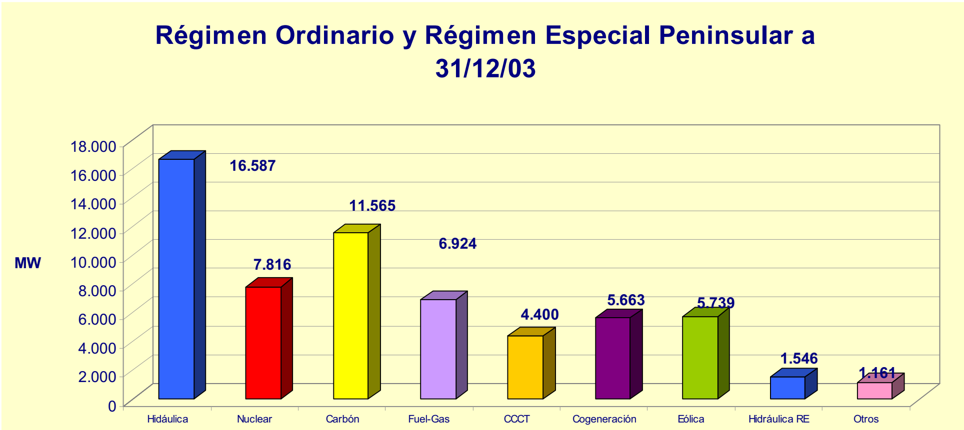


Fig. 13.9. *Installed electric power (Ordinary Regime and Special Regime for Spain 31/12/03). Source: CNE.*

In recent months, there have been increases in installed power in ordinary regime production, derived from the installation of combined cycle plants with gas turbines, with power reductions. With regard to installed power in special regime production, in the last year there has been an increase in annual rates of around 16%, highlighting, apart from the growth of aeolic energy, the relative increases in photovoltaic energy and in the production obtained from primary biomass and biogas. In 2003, 18% of inland Spanish demand was covered by special regime production.

In the distribution of gross inland Spanish production in ordinary regime, the energy representing a lower percentage is from fuel oil facilities, with a participation of around 10%, this depending, in turn, on greater or lesser hydraulicity. Depending on annual hydraulicity, between 55% and 65% of cover would be shared by nuclear energy and energy from coal facilities. Production technologies CO2-friendly (hydraulic, renewable and nuclear) reached a 50% of total generation in 2003.

In this distribution of technologies, it is important to point out that some of them would be more affected than others by atmospheric warming and reduced rainfall. Climate change would particularly affect hydroelectric power plants, due to less hydric supply, and nuclear and thermal power plants, using coal, fuel, gas and combined cycles, as all of these are subjected to a reduction of efficiency with higher temperatures. In this sense, the projection presented by Ayala-Carcedo (2003) is interesting, dealing with the evolution of flows in national basins for the year 2060, and the subsequent repercussions of nuclear power plants. Therein, the author calculates a reduction of 57% for that year in the Guadiana I basin, of 34% in the Guadalquivir basin and of over 28% in the Segura, Júcar and Duero basins, for example.

The capacity installed in Spain in the year 2003, distributed throughout Regional Autonomies, shows that it is still Catalonia, with over 10,000 MW, the region with most capacity installed, mainly produced by nuclear and hydraulic facilities. Catalonia is followed by Castilla y León (with over 8,500 MW installed) and Galicia (with over 7,000 MW), from conventional hydraulic and thermal power.

The Regional Autonomies of Madrid, La Rioja, Melilla and Ceuta are the ones with the least installed capacity, less than 500 MW.

The new systems of generation are generally located in the zones showing a deficit, like the Central Zone, the Mediterranean Coast and the South. However, with regard to this correlation trend of the existing imbalances between generation and demand, tendencies in the opposite direction can be observed. Thus, it must be said that there are zones that traditionally show a surplus in production, and big increases in new generation are predicted, like the regions of Galicia and Aragón. Figures 13.10 and 13.11 show the distribution in Spain of the different electricity power stations.

Fig. 13.10. *Thermoelectric and nuclear power plants. Source: REE.*

13.4.1.2. The transport of electricity

The electric energy transport network should be designed and planned in such a way that, in the operation of the electrical system, the continuity of the supply is guaranteed in the necessary conditions.

With regard to the development needs of the transport network, it has already been shown that the biggest increases occurred in the South, Mediterranean Coast and Centre, and this trend is expected to continue in the next few years.

Table 13.4. *Evolution of the transport system, in km. Source: REE, Advance of the Report 2003.*

Year	400 kV	220 kV
1999	14.538	15.900
2000	14.918	16.003
2001	15.180	16.178
2002	16.031	16.205
2003	16.560	16.242

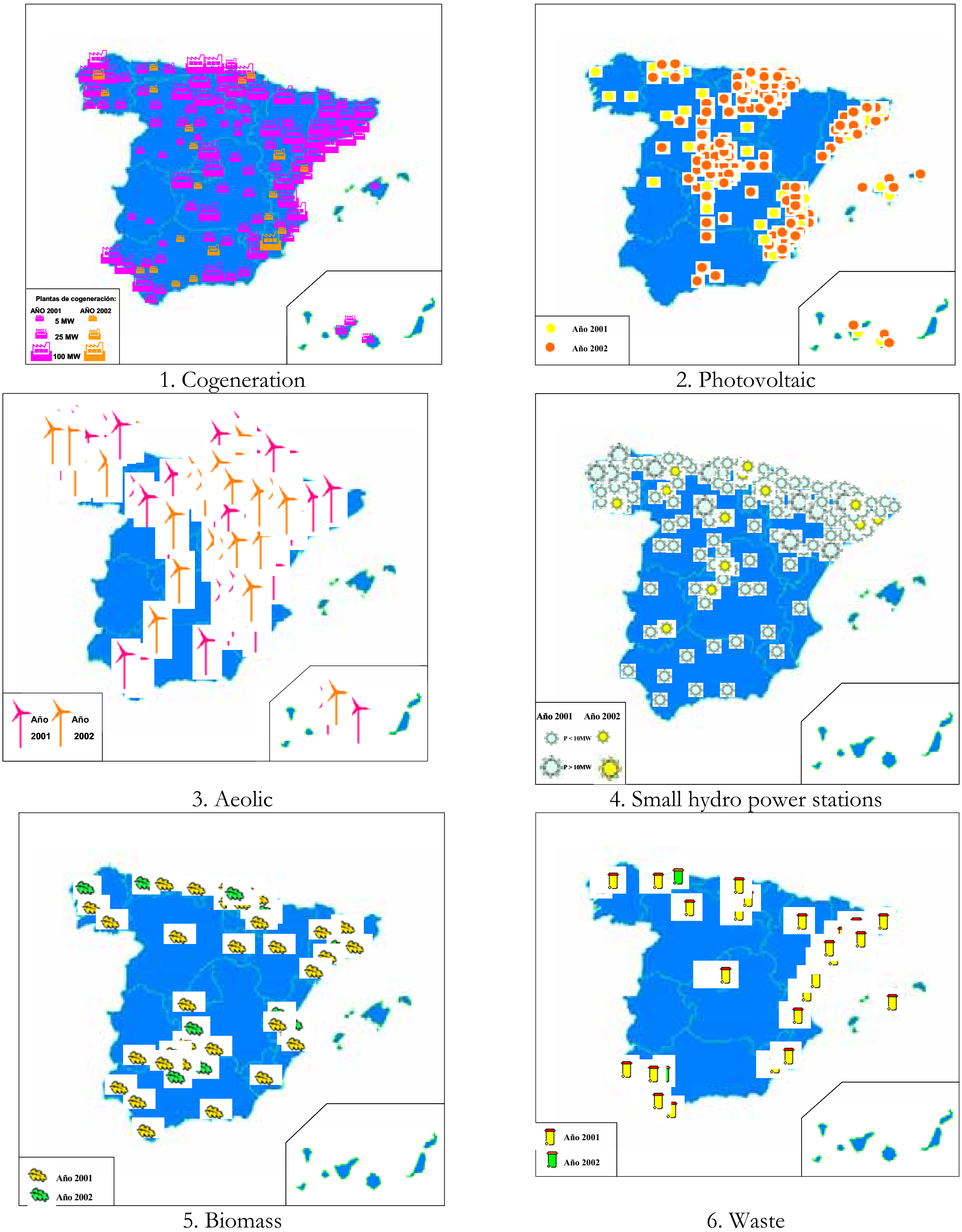


__Fig. 13.11.__ Special regime production facilities. 1) Cogeneration; 2) Photovoltaic; 3) Aeolic; 4) Small hydropower station; 5) Biomass; 6) Waste. Source: CNE.

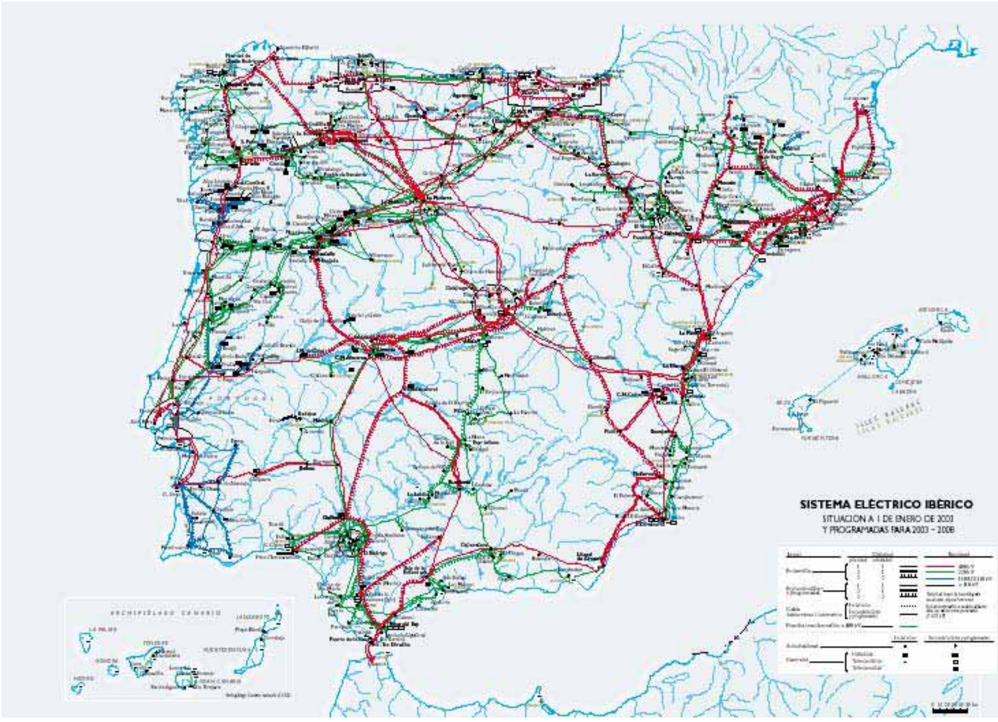


Fig. 13.12. *Electric energy transport network. Source: REE.*

13.4.2. Natural gas

13.4.2.1. The supply of natural gas

The supply of natural gas is done by means of the regasification plants and the connections by gas pipeline with Morocco, France and Portugal. There is also a small level of domestic production.

Table 13.5. *Production capacity of Spain's gas deposits. Source: ENAGAS*

Deposit	Production capacity m3 (n)/h	Production capacity TWh/year
Marshes (Guadalquivir valley)	4.600	0,47
Aznalcazar (Guadalquivir valley)	1.141	0,12
Poseidón (Gulf of Cádiz)	53.000	0,54
TOTAL	**58.741**	**3,65**

Table 13.6. *Current capacity of Spain's regasification plants. Source: ENAGAS*

Regasification plant	Storage capacity $m^3(n)/h$	Vaporisation capacity $m^3(n)/h$	maximum days autonomy (*)	Docking capacity m^3 LNG	Load capacity tanker trucks/day
Barcelona	2 x 40.000 2 x 80.000 Total 240.000	600.000 (72 bar) 600.000 (45 bar) Total 1.200.000	4.5	1 x 80.000 1 x 140.000	50
Huelva	100.000 60.000 Total 160.000	400.000 (72 bar) 50.000 (45 bar) Total 450.000	8	140.000	50
Cartagena	55.000 105.000 Total 160.000	450.000	8	140.000	50
Bilbao	2 x 150.000 Total 300.000	400.000	16.8	140.000	15
TOTAL	**860.000**	**2.500.000**	**7.7**		**165**

(*) The days of autonomy are calculated as the days needed, regasifying to maximum capacity, to consume the gas from the full tanks, discounting minimum filling capacity (10%).

13.4.2.2. Network of gas pipelines

Gasification in Spain is in the expansion phase. The situation of the transport network in November, 2003, is shown in table 13.7.

Table 13.7. *Gas pipeline network in Spain. Source: CNE.*

Company	Km of gas pipeline
ENAGAS	5.904
AL-ÁNDALUS (ENAGAS +TRANSGAS)	277
GASODUCTO DE EXTREMADURA (ENAGAS +TRANSGAS)	250
GAS NATURAL SDG	209
GAS EUSKADI TRANSPORTE SAU	152
TRANSPORTISTA REGIONAL DEL GAS	41
INFRAESTRUCTURAS GASISTAS DE NAVARRA	13
TOTAL	**6.846**

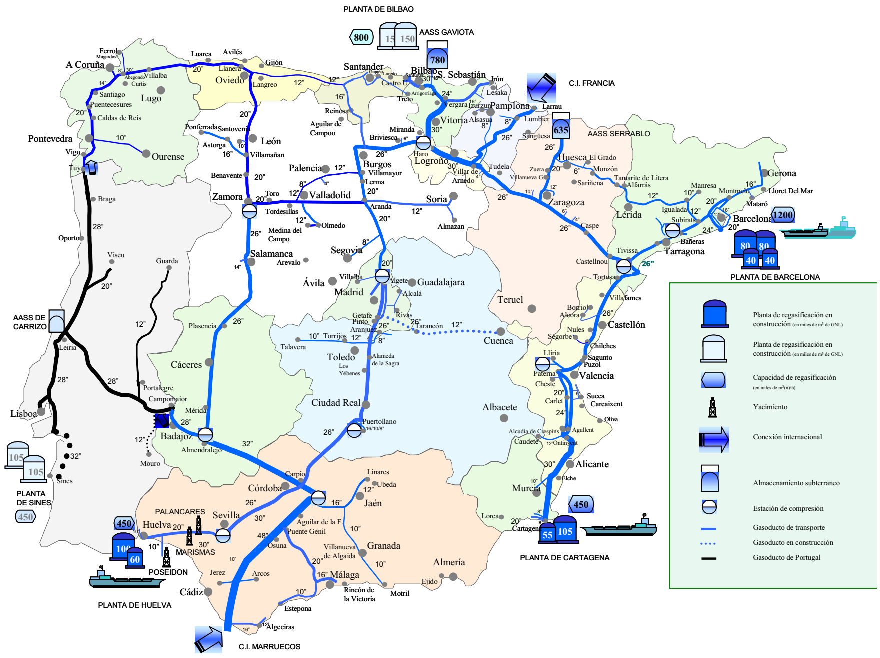


Fig. 13.13. *Map of gas infrastructures. Source: CNE*

13.4.3. Oil and derivatives

13.4.3.1. Network of multi-fuel pipelines, refineries and deposits.

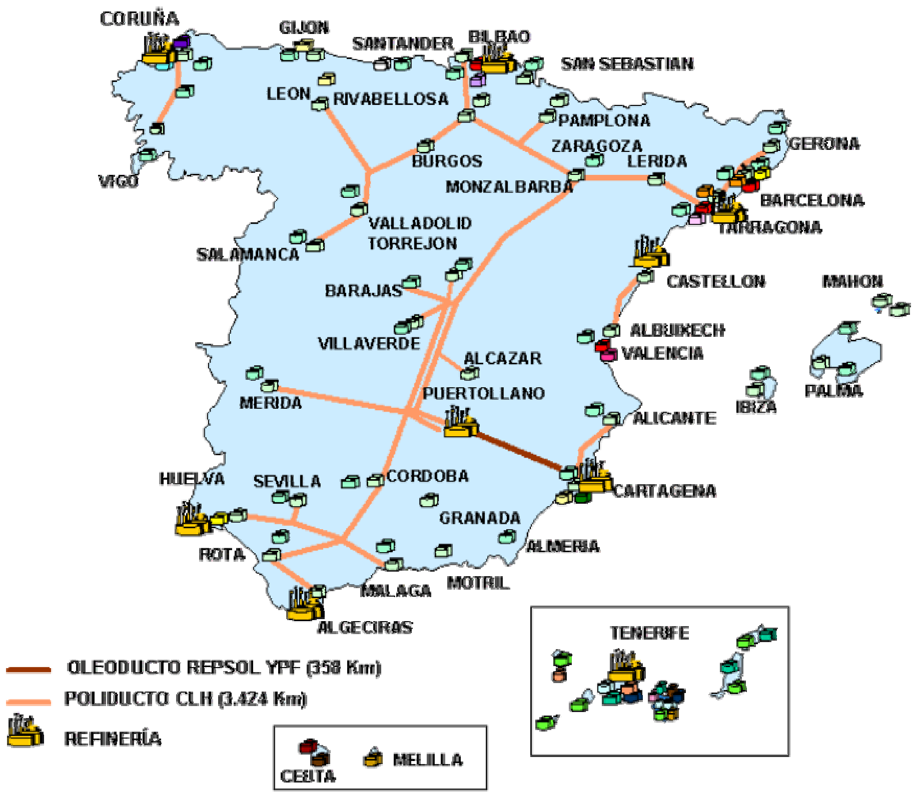


Fig. 13.14. *Network of multi-fuel pipelines, refineries and deposits of oil products. Source: CLH.*

13.5. MAIN ADAPTATIONAL OPTIONS

Depending on the scenario considered, there are certain possibilities for adaptation. In Spain's energy policy certain measures exist, and others are being adopted, in an attempt to avoid or mitigate the effects of climate change.

These measures are reflected in the different documents intended either to promote or improve determined instruments aimed at environmental protection – like, among others, renewable energy or energy efficiency – or with this type of objectives in mind but which also incorporate environmental improvements. The most relevant actions are now indicated, with a brief description of each one.

Plan de Fomento de las Energías Renovables (PFER) – plan for the promotion of renewable energies-, approved by the government on December 30th, 1999. It established the necessary growth objectives in each one of the technologies considered as renewable in order for their production to represent 12% of Spain's consumption of primary energy in the year 2010.

Estrategia Española de Ahorro y Eficiencia Energética 2004-2012 (E4) – Spanish strategy for energy saving and efficiency-. Started in October, 2002, and approved by the Council of Ministers on November 28th, 2003. Aimed at promoting energy saving and efficiency and, indirectly, at guaranteeing the energy supply, by reducing imports, increasing the competitiveness of the production sectors and by helping to reach environmental objectives, which is compatible and in line with the main vectors of Spanish energy policy. This document analysed the possibilities for energy saving and efficiency in different sectors, such as construction, transport, public services, industry, tertiary and residential, the energy transformation sector (refinery, electricity production and cogeneration) and the agriculture sector.

Estrategia Española de Lucha contra el Cambio Climático (EECC) – Spanish strategy for climate change-: this is the oldest, as it was initially drafted in 2001, with the creation of the *Oficina Española de Lucha contra el Cambio Climático* – Spanish office for climate change- and the redefinition of the *Consejo Nacional del Clima* –national council on climate-. It was approved on February 5th, 2004 at the Plenary Meeting of the National Council on Climate, pending approval by the Council of Ministers. Its general objective is to contribute to fulfilling the compromises derived from the Kyoto Protocol, specifically the one related to the limitation of the growth of net greenhouse gas emissions to 15%. The Strategy enumerates over 400 measures to be applied in different sectors, such as energy production and transformation, industry, transport, the residential, commercial and institutional sectors, agriculture, livestock farming and waste. It also proposes a series of measures for the promotion of sinks. Lastly, the strategy contemplates Directive 2003/87/CE on the emission trading allowances, which affects almost half the emissions of greenhouse gasses in our country.

Estrategia Española de Desarrollo Sostenible (EEDS) – Spanish strategy for sustainable development-, the drafting of which began in November, 2001, can be considered as the most important of all, because it encompasses the others, due to the fact that it must jointly analyse the economic, social and environmental vectors of society. There is an Advisory Document which appears to make a good diagnosis of the situation (innovation, technology, population ageing, territorial imbalances, sustainable water management, poverty and social exclusion). The document also established measures and instruments such as follow-up and evaluation indexes. It is still in the draft phase, however, and their is no set date for final approval, and it can therefore only be considered as a framework of intentions.

Documento de Planificación de los Sectores de Electricidad y del Gas Natural – planning document for the electricity and natural gas sectors- Development of the transport networks

2002-2011, approved by the Government on September 13th, 2002. It includes, among others, forecasts of the future behaviour of demand, the resources necessary to satisfy this, the evolution of market conditions in order to guarantee supply and the criteria for environmental protection. These forecasts are part of the indicative planning, specified in the Electricity Sector Law, which established the exception of transport facilities, in which planning is of a binding nature. With regard to environmental protection, on one hand, it integrates the objectives of electricity production of the PFER, and extends these, and on the other, assumes the need to reduce final energy consumption, leaving the measures to be applied to the drafting of a specific document, which was finally drawn up In the previous E4.

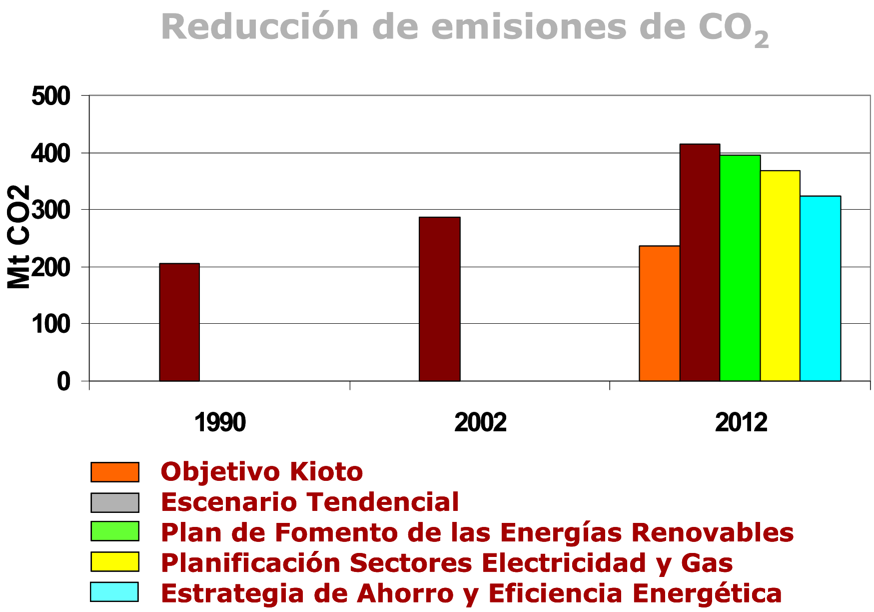


Fig. 13.15. *Forecast of reduction of CO2 emissions (red: Kyoto Objective; grey: tendency scenario; green: promotion plan of renewable energy sources; yellow: planning electricity and gas sectors; blue: strategy for energy saving and efficiency). Source: E4 Economic Report. Economy Ministry.*

Beyond the regulatory options described, another, equally important one could be considered, developed on an international level for the last few years by the risk managers of companies exposed to climatic hazards. It involves the introduction into the financial markets of products related in some way to climatic parameters, such as wind, temperature, rainfall, etc., or any combination of these. Thus, de Paz Cobo (2003) points out that in the 1996-2001 period, over 4,700 contract were signed, to an accumulated total of 7,500 million US dollars. Their main characteristic is the cover of risks associated with climate, for example, a decrease in electricity consumption owing to an excessively warm winter. Obviously, the electricity companies are the main parties interested in this type of operations, which, although they are very new in Spain, should not be ruled out as an instrument of cover.

There should also be more actions for the improvement of bioclimatic housing development, in order to construct buildings and entire cities based on a substantial improvement with regard to energy efficiency.

13.6. REPERCUSSIONS IN OTHER SECTORS OR AREAS

It is not easy to find updated statistical information[1] that describes in a sectorial way final energy consumption in Spain, despite in 1998, Red Eléctrica Española published the "Atlas of electricity demand in Spain" (INDEL Project)" presenting grouped sectorial data on demand (residential, commercial, tourism) up to 1997. This situation is a great hinderance to the study of the effects of climate change on energy consumption in the different sectors of the Economy. In the book "Energy in Spain 2002" (Ministerio de Economía 2003a), very aggregated and partial information is presented in relation to the destination of the energy consumed, with the noteworthy absence of electricity (see, however, Valor *et al*. 2002). Table 13.7 summarises the sectorial distribution of final energy consumption in Spain (total, coal and oil products), highlighting the clear incidence of industry and transport.

Table 13.7. *Sectoring of final energy consumption in Spain. Source: Misnisterio de Economía (2003)*

	2001		2002		2002/01
Final consumption	oekt.		oekt.		%
Industry	34.898	37,2	35.634	37,3	2,1
Transport	33.785	36,0	34.377	35,9	1,8
Different uses	25.187	26,8	25.619	26,8	1,7
Total	93.870	100,0	95.630	100,0	1,9
Final coal consumption*					
Iron and steel	1.712	67,3	1.702	68,5	-0,6
Cement	184	7,2	151	6,1	-18,0
Rest industry	584	23,0	579	23,2	-0,8
Domestic uses	65	2,5	55	2,2	-16,0
Total	2.544	100,0	2.486	100,0	-2,3
Final consumption of oil products*					
Petroleum liquefied gasses	2.633	4,6	2.646	4,6	0,5
Gasolines	9.084	15,9	8.791	15,3	-3,2
Kerosenes	4.734	8,3	4.460	7,7	-5,8
Gas-oil A+B	23.658	41,3	24.904	43,2	5,3
Gas-oil C	4.224	7,4	3.849	6,7	-8,9
Others	12.922	22,5	12.984	22,5	0,5
Total	57.255	100,0	57.635	100,0	0,7

(*) Excluded uses for generating electricity.

A good procedure for determining the sectorial impact of energy consumption is through the well-known Input-Output Tables of the Spanish economy which show in detail the relationships (bidirectional) between the demand of all the sectors involved. Specifically, it would be interesting to determine, with the use of these tables, the relationships between the energy sector and all the other economic sectors (labandeira and Labeaga 2002). Alcántara and Padilla (2003) have published an interesting study which, following this methodology, classifies the economic sectors according to their relationship with the energy sector. The information refers to the year 195. Table 13.8 presents the classification of the economic sectors according to their relevance with regard to energy consumption.

The behaviour of the economic sectors in relation to energy consumption is summarised in the four quadrants of the table. Specifically, and schematically:

[1] In 1998, Red Eléctrica Española published the "Atlas of electricity demand in Spain" (INDEL Project)" presenting grouped sectorial data on demand (residential, commercial, tourism) up to 1997.

- The sectors appearing in quadrant B are those that have an energy consumption and, in turn, give rise to a high consumption rate by the other sectors.
- Quadrant C presents the opposite extreme, that is to say, it encompasses the sectors that are irrelevant or negligible with regard to energy consumption, both as a result of their own activity and of their influence in the energy consumption of the other economic sectors.
- Quadrant A includes the sectors whose energy consumption is sensitive to increases in demand by the economy, but which, in turn, do not affect the energy consumption of the other sectors.
- Finally, quadrant D presents sectors whose activity clearly affects the country's final energy consumption, but which do not respond with an increase in energy consumption along with an increase in general economic activity.

Table 13.8. *Relevance of economic sectors in relation to energy consumption (data from 1995)*
Source: Alcántara and Padilla (2003) and own design

A) Sectors with energy consumption sensitive to increases in the final demand of the economy	**B) Very relevant sectors (they consume more energy with increases in final demand by the economy; with increases in their own demand, the cause the other sectors to consume more energy)**
Non-metal products Energy Agriculture	Internal transport Chemicals Construction Iron and steel and non-iron metallurgy Other transport
C) Non-relevant sectors (with little effect on final energy consumption, and, in turn, not very sensitive to changes in the final demand of the economy)	**D) Sectors whose activity clearly affects the final energy consumption of the economy**
Paper and printing Textiles and footwear Trade Metal products Other manufactured products Other services on sale	Foodstuffs(*) Transport equipment Other non-sale services Restaurants and hostelry

(*) The Foodstuffs sector is situated on the boundary between quadrants B and D.

13.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

This epigraph attempts to indicate the elements that are currently unknown to the researchers. A synoptic table was designed which attempts to summarise the degree of knowledge of the impact of a change in a given climatic parameter on the different energy sources. We should highlight an interesting aspect here, which is the relationship existing between the degree of knowledge of the impact and the importance of the energy source (and the use made of it) considered. So, for example, everything related to the generation of electricity, using hydraulic or aeolic methods, entails a high degree of knowledge, whereas the effect of wind on the marketing of natural gas is totally unknown, beyond speculation.

Table 13.9. *Main uncertainties and knowledge gaps with regard to the influence of climate change on the energy sector*

		Rainfall		Temperature		Wind		Others
		Increase	Decrease	Increase	Decrease	Increase	Decrease	
Electricity	Generation	3	3	1	1	3 (aeolic)	3 (aeloic)	3 Insolation (solar)
	Transport and distribution	2	2	3	3	3	0	
	Marketing/ demand	1	1	3	3	0	0	2 (Combination Temperature/Humidity and Temperature/Wind)
Natural Gas	Supply	1	1	0	0	0	0	
	Regasification	0	0	1	1	0	0	
	Transport and distribution	1	1	1 (open-air oil pipelines)	1 (open-air gas pipelines)	0	0	
	Storage and Supply	1	1	2	2	0	0	2 (Combination Temperature/Humidity and Temperature/Wind)
Oil	Refinery	1	1	1	1	0	0	
	Transport and distribution	2	2	2	2	0	0	
	Marketing	1	1	2	2	2	0	
Coal	Extraction	1	1	1	1	0	0	
	Storage	2	2	2	2	2	2	
	Marketing	2	2	2	2	0	0	
Non electrical renewable sources	Production	2 (biomass)	2 (biomass)	1	1	0	0	2 (Low-intensity solar)

Degree of knowledge of the impact: 1 low, 2 medium, 3 high, 0 unknown
Note: measurement of the degree of knowledge was based on research into the impacts on the sector or subsector analysed; many of the effects classified in Table 13.2 as neutral are obvious, and they have therefore not been contrasted empirically (thus, the 0)

13.8. DETECTING THE CHANGE

13.8.1. Electricity

Temperature increases give rise to much milder winters and much hotter summers. An increase (decrease) in demand combined with this temperature effect causes an increase (decrease) in the power needed in summer (winter). This effect has been seen, year after year, in the approximation of the peak power demand in summer to winter values.

Likewise, reduced rainfall implies a reduction of hydroelectric producible and a consequent increase in the market prices of electricity.

Furthermore, the increase in extreme storm episodes can negatively affect the availability of transport and distribution of energy, which is detected with the use of classical quality indicators: Iceit (annual interruption time of electricity supply) and Icein (number of annual interruptions of the electricity supply). However, investments in the quality of the service lead to better results reflected by these indicators.

With regard to electricity consumption, possible changes in domestic consumption habits should be taken into account, as has been detected over the last 20 years. The scatter Figures are now shown, with a polynomial fit in each case, which reflect the relationship between daily electricity demand on working days and the ITE in 1983, 1993 and 2003. The result is presented in Figure 13.17 It is obvious that there has been a clear modification of this consumption structure, caused by the displacement to the right and upwards of the dots corresponding to the summer, an effect that should be attributed to the increasingly generalised use of air conditioning machines, according to data supplied by the Asociación de Fabricantes Españoles de Climatizadores (AFEC) which also responds to an increase in the standard of living.

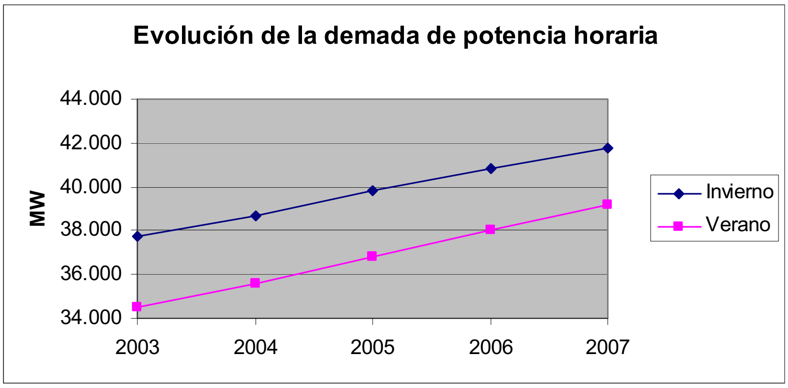


Fig. 13.16. *Evolution of forecasted hourly power demand (blue: winter; red: summer). Source: CNE*

Thus, the indicators related to electricity proposed for the possible detection of climate change are the following, but we must keep in mind that there are other components that can affect these.

- Demand peaks in summer. Relationship between the winter/summer demand peak
- Degree of utilisation of hydraulic energy in generation
- Price of electricity (spot price and forward price)
- Iceit, annual interruption time of electricity supply
- Icein, number of annual interruptions of the electricity supply
- Domestic electricity consumption:
    - In cooling
    - In heating
- Industrial electricity consumption
    - Used for cooling
    - Used for heating
    - Used for energy in the processes

It should be pointed out here, however, that these detectors should be contrasted. Thus, for example, in relation to the Iceit, it will only be effective if the causes therein are broken down. Simple saturation of the lines by new uses or by higher standards of living leading to greater consumption can give rise to higher values of this indicator, without being directly associated with higher temperature. Therefore, the Iceit, considered globally, would be of no use without a disaggregation of its different components.

It should also be pointed out that increased incomes can lead to a modification of the habits of society in that it can afford more comfort. It would therefore be necessary to analyse the combined effects of *Temperature*facilities*power of use (economic)* in order to reach a truly definitive conclusion. In this sense, it must be pointed out that greater use of air conditioning in the big urban nuclei leads to greater growth of demand for air conditioning, in that these apparatuses generate heat which is expelled outwards, contributing to an increase in external temperature. This same consideration is also valid for automobiles.

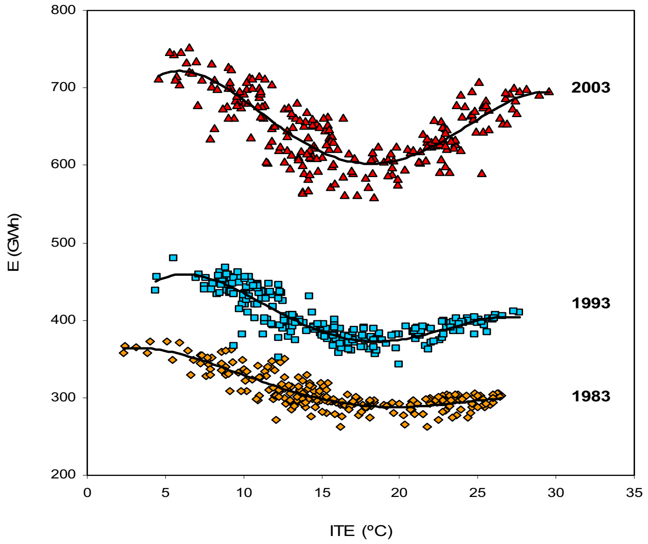


Fig. 13.17. *Scatter Figures of electricity consumption and of ITE 1983, 1993 and 2003 and polynomial fit. Each scatter Figure is similar to the one in the upper, left hand figure in Figure 13.3. Source: own design based on data from INM, INE and REE.*

13.8.2. Global energy demand

The primary energy intensity of the European Union decreased, in accumulated terms, from 1990 to 2000, at a faster rate during the second half of the decade. In Spain, however, this indicator shows the opposite tendency. In Spain, in the year 2000, primary intensity slightly exceeded the average of the EU member states, due to equal purchasing power. In the case of total energy intensity (consumption of total energy per GDP unit), represented in Figure 13.18, the tendencies recorded are qualitatively similar (upward in the case of Spain and downward in the case of the EU). Since 1990, the average annual growth rate of final intensity in Spain has been 0.8%. Part of this growth is due to a higher electricity consumption rate as a consequence of greater use of air conditioning systems.

Some possible general energy indicators of climate change could therefore be the following:

- Total energy consumption
- Total energy intensity
- Current number of air conditioning systems sold.
  In this sense, it should be mentioned that the increase in annual sales of air conditioning systems does not only respond to a temperature increase, but also to a progressive reduction of the prices of these and to the higher standard of living of the Spanish, which can be seen in an increased desire for comfort.

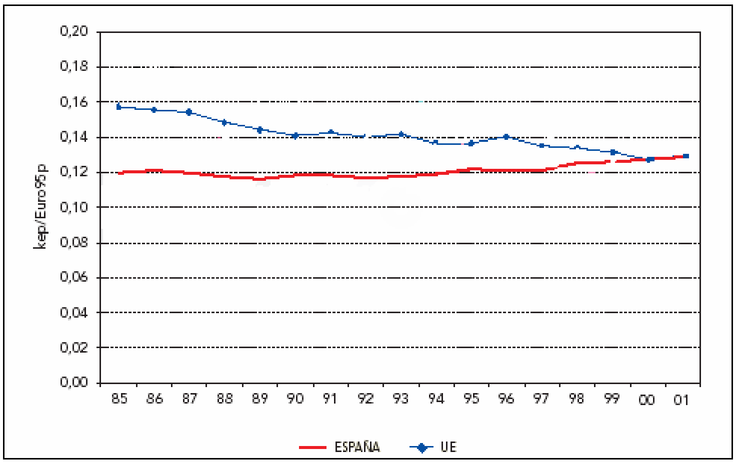


Fig. 13.18. *Evolution of total intensity in Spain and in the EU 1985-2001. Purchasing power parity (the GNP referred to constant prices in 1995). Source: Ministerio de Economía (2003).*

13.9. IMPLICATIONS FOR POLICIES

Up to now, the European commission has proven to be the most effective administration for defining environmental objectives, and recently, objectives related to energy, too. In this sense, we must remember that the Rome Treaty, in section 2, establishes that "the community will have the mission of promoting (...) a high level of protection and improvement of environmental quality, (...)", and section 174.2 states that "community policy in the environmental sphere must aim to reach a high level of protection, keeping in mind the diversity of existing situations in the different regions of the Community. The principles of caution and preventive action will be used as a base, (….)" . Likewise, section II-37 of the future European Constitution stipulates that "Union policies, based on the principle of sustainable development, will integrate and guarantee a high level of protection of the environment and an improvement in quality thereof".

In this sense, the European Commission, concerned about energy efficiency and environmental questions, promotes the liberalisation of the energy sector without any delay in the adoption of Directives of an environmental nature, in order to attain the sustainable development of the energy sector within its sphere. Recently, very important Directives have been approved, such as:

- *Directive 2001/80/CE, from October 23rd, by the European Parliament and the Council, on the limitation of emissions into the atmosphere of determined contaminating agents from large combustion facilities.* This Directive revises Directive 88/609/CEE, imposing more demanding limits on the emission of SO_2, NOx and particles, affecting both existing and new facilities, in this last case, after the year 2008. Its objective is to reduce emissions of SO_2 by 63% and NOx by 21% in the EU. This Directive also establishes limits for gas turbines and for biomass.

- *Directive 2001/81/CE, from October 23rd, by the European Parliament and the Council, on national thresholds for the emission of determined atmospheric pollutants,* the aim of which is to fight against acidification, tropospheric ozone and eutrophication in each country, taking into account the concept of critical load. It establishes for each country maximum emissions of SO_2 and NOx from 2010 onwards.

- *Directive 2001/77/CE, from September 27th, by the European Parliament and the Council, related to the promotion of electricity based on sources of renewable energy on the internal* *electricity market,* aimed at reaching 12% of gross national energy consumption in 2010, and specifically reaching 22.1% of electricity based on renewable sources with regard to the total electricity consumption in the Community for this same year.

- *Directive 2002/91/CE, by the European Parliament and the Council, from December 16th, 2002, related to energy efficiency in buildings,* affecting both new and old buildings and aimed at promoting performance in relation to energy in buildings in the EU, attempting to reach a high level of cost effectiveness. To this end, it establishes an efficiency calculation methodology, certain minimum requirements, energy certification and the inspection of certain integrated elements of the air conditioning systems in buildings.

- *Directive 2003/30/CE from May 8th, 2003, by the European Parliament and the Council, relating to the promotion of the use of biocarburants and other renewable fuels in transport,* aimed at substituting diesel and gasoline sold for transport by a minimum percentage of biocarburants, 2% for 2005 and 5.75% for 2010.

- *Council Directive 2003/96/CE, from October 27th, 2003, aimed at restructuring the community taxation systems for energy and electricity products,* defining a general taxation system for energy products, in order to improve the functioning of the internal market, to favour the protection of the environment and to promote better use of labour.

- *Directive 2003/87/CE by the European Parliament and the Council, from October 13th, 2003, which establishes a system for greenhouse gas emissions trading in the Community,* modifying Council Directive 96/61/CE. This regulation introduces a market mechanism for facilitating the fulfilment of the compromises derived from the Kyoto Protocol at Community level, to be initiated in 2005 and intended to be fully operative by 2008.

- *Directive 2004/8/CE, by the European Parliament and the Council, related to the promotion of cogeneration, based on the demand for useful heat on the internal energy market,* promoting this technology and establishing the need to guarantee the origin of electricity from cogeneration.

At the same time, the European commission is concerned about the security and sustainability of the energy supply, and therefore inaugurated, at the end of 2002, a debate on the subject with the use of a Green Book. The European Commission analyses separately the two facets of energy provision, supply and consumption, both of which must form part of the common energy policy, aimed at sustainable energy supply and consumption.

It is in the consumption aspect, however, -control of energy demand- in which the Green Book considers that there is greater potential for the establishment of efficient strategies. To this end, it recommends several actions, among which are highlighted a strengthening of the liberalisation processes – in order to inform the consumer of the price signal-, the establishment of mechanisms to ensure that these prices reflect real costs, and the promotion of energy saving. Lastly, it suggests the intensification of efforts in two increasingly developing and intensive energy sectors, which, however, have great potential for improvement: transport and construction. The Green Book suggests changes in means of transport along with the adoption of additional measures aimed at increasing energy saving in buildings. The EU's energy policy therefore seems to be the correct one with regard to attaining sustainable energy development.

With regard to Spain, a series of positive measures has been adopted to date aimed at making our energy development more sustainable. Spain's energy policy, in accordance with the sectorial Laws on electricity and hydrocarbons, coincides with that of the EU in relation to the following three objectives:

1. Security of the supply
2. Liberalisation and competitive markets
3. Protection of the environment

To date, this energy policy has led to the following regulation:

- *Total liberalisation of the electricity and gas supply in 2003.* Wholesale markets have been created (organised and free), along with retail markets (based on contracts with suppliers). All consumers have been given the capacity to choose their electricity supplier. All this is intended to lead to improved economic efficiency, and in the case of the electricity sector, given our current generation structure, to improved energy and environmental efficiency.

- *The Plan de Fomento de las Energías Renovables* –promotion plan for renewable energy sources- the objective of which is to provide, through these sources, 12% of the primary energy consumed in 2010.

- *The Documento de Planificación de los Sectores de Electricidad y del Gas Natural 2002-2011*–planning document for the electricity and natural gas sectors-, analysing the cover of the supply over ten years, with the fulfilment of the environmental objectives (with regard to renewable energy and cogeneration).

- *The regulation of the electricity sector aimed at supporting renewable energy and cogeneration*; this has proven to be efficient up to now, taking into account the huge development of aeolic energy, energy from small hydropower stations and cogeneration. The promotion system is based on giving these technologies a relevant premium above electricity market prices. The amount of the equivalent premium can be evaluated in 2003 at almost € 1.000 millions, which is an average surcharge for the electricity consumer of 7%, which is a solid backup for the new generation of clean and efficient technologies.This regulation, however, has not yet managed to develop biomass and thermal solar energy. The recent RD 436/2004, from March 12th, attempts to improve this situation.

- *Liberalisation of the generation activity*. As a consequence of this, of technological development and of the new environmental Directives, new combined cycle plants are being incorporated, which make use of natural gas, and the global energy performance of electricity generation is therefore improving, and specific emissions are being reduced.

- *Integral rates and rate aids that quantitatively modify consumption habits* (the hourly power rate and complements for hourly and curtailability discrimination). The experience of the system operator in the application of these regulatory elements during the episodes of extreme demand and partial power cuts on December 17th, 2001, was very positive. The current rates structure, however, contains inefficiencies that can be improved.

-
- *In the Royal Decrees on rates in the years 1995, 1997 and 1998 an approximate allowance of around 32 million Euros (5,300 million pesetas) was destined to the demand management programmes.* The experience was generally positive, because with most of the actions, based on economically encouraging the penetration of new consumption-efficient technologies (like low-consumption bulbs, class A type domestic appliances, motor regulation systems or heat pumps) certain energy savings were made that paid off these incentives in very few years. These programmes, however, were interrupted, and it was not until 2004 that the Royal Decree on rates once again considered an allowance for this concept of 10 million Euros, one third of what was previously established.

Nevertheless, it is still necessary to consider the current regulation system in order to develop the policies in force. Among other aspects, we should:

- Develop the specific rules for the connection and operation of the production facilities in the special regime.
- Incorporate the Directives on cogeneration and emissions trading.
- Establish specific mechanisms for the implementation of actions provided for in the E4.

In short, it seems that we are on the right path with regard to energy policies, both in the EU and in Spain, but our energy development system, however, is far from being sustainable. We therefore must study these policies more profoundly in order to adopt additional and specific measures to implement strategies, aimed at making our energy development system sustainable; in the case of Spain, it seems that the nuclear option should be at least studied to help reaching the target, complemented with other CO2 free strategies.

13.10. MAIN RESEARCH NEEDS

Whereas the effects of energy consumption on the emissions of greenhouse gasses and on global warming have been subjected to countless studies, as indicated by the IPCC (2001), there have been very few studies that have dealt more deeply with the effects of climate change on energy demand. The relationships between climatological variables and energy use have been studied by different authors (Quayle and Diaz (1979); Le Comte and Warren (1981); Warren and LeDuc (1981); Badri (1992); Yan (1998); Lam (1998); or Pardo *et al* (2002), among others), but, as Ruth and Amato (2002) pointed out, there are few analyses to date dealing with the long-term implications of climate change in the behaviour patterns of energy use and the consequences for the associated investment decisions.

The biblioFigureic review reveals multiple foreseeable effects, but also great variability with regard to consequences; thus, for example, Segar *et al* (1992) estimate that energy demand during summer peaks will rise in Israel by 10% as a result of temperature increases of 4º C, whereas Cartalis *et al* (2001), in the case of Greece, estimate that a 1ºC increase would cause a decrease in the demand for heating of 10%, compared with 28.4% in the demand for cooling. Sailor (2001), quoted in Ruth and Amato (2002), states that a 2º C temperature increase would cause an increase in electricity consumption per capita of 11.6% in Florida compared to a decrease of 7.2% in Washington; Warren and LeDuc (1981) made an estimate of the consumption and prices of natural gas in new areas of the USA, finding significant differences between them.

This series of quotes leads us to a fundamental conclusion, perhaps the most important one of this epiFigure: we need to learn more about the effect of climate change on energy demand at regional level and according to economic sectors. All of this is due to different reasons:

1. Generalist scenarios of climate change can lead to big losses of information; thus, in Spain, we should learn whether the foreseable mean temperature increase will be homogeneous, or whether it will affect some regions more than others;
2. It is not only important to learn of the effect of mean temperature, but also of the effect of maximums and minimums;
3. Local infrastructures are different at regional level; increased maximums on the Cantabrian Coast would have a different impact than on the Mediterranean Coast, due to differences in the facilities. In this sense the EIA Report (1999) is interesting, and points out that only 8% of family residences in New England have air conditioning, compared with a national average of 47%;

4. With regard to the series to the indicators proposed for the detection of climate change in relation to the energy sector, there is a need to design models that make a disaggregation of the different elements affecting the evolution of these.
5. Specifically, we need to discern between the income/wealth effect and the temperature effect in the summer period, according to regions, in order to correctly identify the possible effect of climate change.

It is therefore vital, on one hand, to generate medium and small scale scenarios of climate change, in order to simulate the effects on energy demand, and on the other, these scenarios will provide estimates of supply and the structure of this, basically related hidraulicity, wind and rainfall. From the first two will come the direct components of the supply structure, whereas the third one (subtracting the effects on hidraulicity) will provide estimates of the form of energy distribution.

It is also very important, considering that one of the effects of an increase in the mean temperature of the earth is a rise in sea level, to study the possible effects on energy demand of the construction of centres for the mitigation of these effects. In a country like Spain, with three quarters of our territory surrounded by sea, these effects could be very serious.

We require a more in-depth study of the effects of climatological variables on energy demand at national level; thus, to date, only the articles by Pardo *et al* (2002), Torró *et al* (2001), Valor *et al* (2001a)(2001b) and Climent *et al* (2003) have dealt with the question. And always from an average and global perspective, that is to say, using the medium temperature value as an indicator, and at national level, using four local weather stations (Madrid, Valencia, Bilbao and Seville); The main reason given by the authors (for example Climent *et al* (2003)) was the non-disaggregation of energy demand at regional and sectorial level. This is precisely one of the main demands by Spanish researchers, because the existing disaggregation, according to regions and sectors of activity is, to say the least, deficient.

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14. IMPACTS ON THE TOURISM SECTOR

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ABSTRACT

The *sensitivity of the tourism sector to climate* is very great in Spain, as our good climate conditions, especially on the Mediterranean coast, are a decisive factor in relation to the geographic areas of choice, activity schedules, tourism infrastructures and the functioning of these and the conditions of enjoyment and wellbeing of the tourist, as well as being one of the main elements of attraction in our country.

The *impacts of climate change* will affect, in the first place, the *geographic-tourism space,* and can cause alterations in the ecosystems involved, which are already in a fragile state, bringing to a halt the social, economic and environmental benefits that have been enjoyed up to now. Water scarcity will cause problems related to the functionality or economic feasibility of certain destinations. Temperature rises could modify activity schedules. A rise in sea level would threaten the current location of determined tourist settlements and of their infrastructures. These changes will have a greater impact in the more deteriorated areas, with a serious imbalance and greater conjunction of the different climatic effects. The *most vulnerable areas* to climate change are along the coast (with a high degree of human intervention), these forming Spain's main sun and sand tourist attraction, and mountain areas, above all in relation to snow tourism.

The *tourism demand* most affected is that related to recreation and holiday tourism (the main type in our country). Tourists will modify their behaviour, reducing their average stay in each destination, delaying the moment in which they decide to travel, and changing their destinations in the case of tourists from abroad, who will remain in their own countries, and in relation to national demand, they will travel to the northern coasts or inland. There may also be an increase in inter-season trips (spring and autumn).

With regard to the *tourism* offer, the biggest impact will be felt by the establishments providing accommodation and the incoming travel agencies at the most affected destinations, with serious economic consequences, especially for those destinations depending heavily on big investments in infrastructures. The most serious consequence for the economy as a whole would *involve reduced income from tourism*, and for the most vulnerable areas, as these suffer from a big imbalance, a foreseeable transformation of the medium and long-term economic conditions thereof and, in the worst of scenarios, the progressive closure of tourism and non-tourism establishments, increased unemployment and the financial ruin of the destinations.

There is great *uncertainty* with regard to the evolution of tourism, and we are unaware of possible variations in the behaviour of demand caused by climate change, or the quantitative level of the impact involved, especially with regard to the loss of a feeling of comfort and safety by the tourists, or the loss of attractiveness of a destination or a travel season. The *possibility of detecting the change* is very limited at present, and the *generation of indicator systems* is vital with regard to indicating and differentiating types of impacts according to types of areas and tourism products, especially coastal and mountain ones. Furthermore, *research needs* in respect to the relationship between climate change and tourism require opening and maintaining *a specific line of research project funding*, with specific programmes dealing with this theme, to be integrated within the National Plan for Research and Development and Innovation (NP R+D+I).

14.1. INTRODUCTION

14.1.1. Uniqueness and demarcation of tourism

Tourism is a complex system which is difficult to delimit, as it comprises a set of different activities of an economic, social, geographic, cultural, sports, environmental and institutional nature. Furthermore, the tourism system is of a transversal and heterogeneous nature, and this makes it unique in a certain way as an activity, due to its close relationship with:

- *Economic factors*: accommodation, transport, food, real estate sector and other complementary goods and services of potential use to tourists.
- *Social factors*: mainly related to the use and enjoyment of leisure time, together with contact with other social spaces and their customs and lifestyles.
- *Natural factors*: referring to the physical environments, like coasts, mountains, inland spaces or those related to protected natural spaces, which are the main components of tourism resources. Climate is a key element of the natural environment in which tourism is developed.
- *Cultural factors*: highlighting the presence of cultural heritage as a tourist attraction.
- *Political factors*: due to the involvement of public institutions in both investment in infrastructures and in promotion of tourist resorts, as well as in the direct participation in regional planning.

The *tourism system* is made up of *four basic elements*: the geographic-tourism *area*, the *demand*, the *offer* and the *agents.* All the fundamental factors and elements interact within a determined institutional and legal framework and in one same location: the *tourist destination*, in which the resources are shared for a determined period of time, which, together with the services used, comprise the tourism offer. Space and time are the two main components of tourism.

14.1.2. Current situation of tourism in Spain

It is well known that Spain has a highly specialised tourism industry, and over the last four decades has become a basic destination for the more developed European countries, and to a lesser extent, of other OECD countries. In fact, together with the United States and France, Spain vies for first place in world tourism, according to figures provided by the World Tourism Organisation (WTO) which indicate that our country receives 7,5% of the 694 million international tourists throughout the world, estimated for the year 2003.

Other countries are appearing in the Mediterranean are now competing with the more traditional destinations in Spain, France and Italy. Among these, we can highlight Greece, with 14 million tourists, Turkey with 12.8 million and Croatia with 7 million in the year 2002, as emerging competitors undergoing inter-annual growth rates higher than in the more traditional countries.

Tourism in Spain is characterised by the volume of demand from the tourism markets involving both residents from foreign countries coming to our country and Spaniards themselves. The most noteworthy aspects of the tourism demand are the reasons for the trip, the destination chosen and the use of accommodation and transport, mainly.

The main flows of *inbound tourism demand* from the international market in Spain during the year 2003[1] are:

[1] The main sources of data on demand are: in physical terms, the Instituto de Estudios Turísticos (institute of tourism studies) belonging to the Secretaría General de Turismo (tourism dept.); in monetary terms, the Bank of Spain, and in relation to hotel accommodation, Instituto Nacional de Estadística (national statistics institute).

- The *foreign visitors crossing our borders* are estimated at approximately 82,6 million.
- The segment of *tourists* (visitors for at least 24 hours) constitutes 63.6% of total visitors, that is, approximately 52.5 million.
- *Revenue from tourism* (according to information supplied by the Bank of Spain) came to a total of 36,871 million euros.
- Foreign visitors accommodated in hotels comes to 27.3 million.
- *Overnight stays* by travellers residing abroad rise to 136.8 million nights.

Considering the effects of climate, it must be kept in mind that of the 52.5 million tourists in Spain, around 40 million come from Central and Northern Europe, and their main reason is to come to a sunny climate close to the coast, a more suitable definition than the traditional sun and sand.

To the demand from abroad, we must add *internal tourism* with big demand flows, which can be of greater quantitative relevance in certain areas than that provided by international inbound tourism. Travel by Spaniards constitutes a big quota of the Spanish tourism market, as their travels are mainly on national territory (Esteban Talaya 2003). The main flows of *tourism demand by Spaniards* during 2003 are:

- Spaniards made a total of almost 129.2 million *trips.*
- *Short trips* to holiday homes which are a very high percentage of the total: 65.25%, with 84.3 million trips.
- The remaining *trips*, called *tourism trips*, amount to 44.9 million.
- *Payments for tourism* made by Spaniards abroad amounted to 7,315 million euros.
- Spanish tourists *accommodated in hotels* in Spain totalled 35.2 million euros.
- The total amount of *overnight stays* made by Spanish travellers in hotels in Spain rises to 91 million nights.

From the *point of view of offer*, Spain has a high number of companies and establishments, making up a highly fragmented and atomised sector, with a wide range of activities. Some interesting representative data on the main subsectors are the following:

- 17,000 hotel establishments with accommodation for approximately 1.4 million.
- 1,200 camp sites, with around 770,000 places.
- 127,000 regulated apartments, with 400,000 bed-places, although dwellings for potential use for tourism are estimated at approximately 5.5 million.
- 9,000 travel agencies, between head offices and branches.
- Another offer: 29 ski resorts, 112 spa resorts, 245 golf courses, 845 national Parks and Protected Natural Areas.

14.1.3. Identification of spaces and tourist destinations

One of the basic features of tourism in Spain is the *diversity* and the *abundance of its resources*, the exploitation of which has given rise to processes of tourism development differentiated in time and in space and to the creation of a large number of products which have shaped an asymmetric map of tourism, in which spaces are identified with unequal intensities in relation to tourism, and which are qualitatively different. Indeed, the exploitation of resources governing the spatial location of tourism is what enables us to differentiate the environments or territorial scopes that are shaped by the tourism function (Vera *et al*. 1997).

At an *initial level of identification* of tourist spaces and destinations in Spain, we refer to the consideration of *geographic environments*, defined both by the nature of the components of the environment and by their territorial function, in each case. Among the geographic conditions outlining the features of these environments, is climate, in first place, which gives peculiarity and diversity to them. The result is the identification of *four environments* which constitute an initial tourist zoning system: *the coastal area*, the *mountain area*, the *rural area* and the *urban area* (López Palomeque and Vera Rebollo 2002).

In Spain, the *coastal tourism area* has been very important since the beginning of mass tourism, and it must be kept in mind that the coast is the environment that houses the biggest offer and the biggest movement of tourists, and which therefore shows the greatest effects of the transformation and restructuring of the territory. The Spanish coastline stretches for 3,904 kilometres on the peninsula and 2,036 kilometres on the islands, which, however, present differentiated environmental conditions and different attractions and possibilities for tourism. In the contrasted realities of tourism and in the different potentialities of this coastline, climatic diversity undoubtedly plays an important role in this environment and throughout the whole country. Initially, in Spanish climatic diversity, we can distinguish the following climates: the Mediterranean climate – with its wide range of nuances and transitions -, the Atlantic climate, the continental climate and the mountain climate.

Apart from the importance of coastal tourism, it must be pointed out that tourism and recreational activities in *urban, rural and mountain areas* have become notably developed, in consonance with the new tendencies of demand, and have been favoured by the responses of the different agents, public and private. This newly found appreciation of the natural and rural environments has opened up new perspectives for tourism as an instrument for the development of economically depressed areas, whereas the urban areas constitute leisure and tourism scenarios, associated with culture and with the global offer, differentiated in each city, allowing for strategies related to the model and the renovation of urban scenery and image (Vera *et al*. 1997). As a result in recent years –and also as a prediction for the future- diversifying tendencies can be seen in the location of tourism, which have important consequences of a territorial, economic and social nature. This process leads to the spatial spread of tourism throughout the whole territory (spatial generalisation of tourism or “touristification” of the territory), a phenomenon which is more observable at intermediate scale (López Palomeque and Vera Rebollo 2002).

Consequently, as an operative outline for this report on the impact of climate change on the Tourism Sector, we have chosen to consider as a *basic zoning system* of reference the four aforementioned environments. On a map of Spain it is easy to identify schematically the four tourism environments, although this scale of analysis presents a degree of abstraction that hides the heterogeneity and specific problems of each one of them, from both the formal and the functional perspectives, and above all, with regard to their environmental contrasts and climatic diversity. And it also hinders the analysis of the differentiated potential impact of climatic change on the different environmental zones of one same environment.

In order to deal with the coastal area, the following zones were considered: the Mediterranean coast (northern, central and southern), the Atlantic coast (Cantabrian, North Atlantic and South), the Balearic Isles and the Canary Isles. For the treatment of the rural area, we refer in each case to the most noteworthy geo-tourism zones of inland Spain; in the case of the mountain area, we considered the biggest massifs, accommodating snow-based tourism, and in relation to the urban space, mention is made of the most significant cities housing Spanish tourism. It must be added that, in using this zoning system, greater attention will be paid to those zones most vulnerable to climate change, and greater priority will consequently be given to references to the *coastal zones and products* (see section 14.4.2) and to the *mountain zones and products* (see section 14.4.3).

Besides, this zoning is completed, where necessary, with considerations of other types of spatial units in each one of the environments. On one hand, the *geotourism zones,* drawn up according to different circumstances, from purposes of business operativeness, image or promotion of tourism policy, to the existence of certain spatial relationships and components, giving the territory the category of functional specialisation or a homogenous nature. For instance, on the coast, the Costa Brava, the Costa Daurada, the Costa Blanca or the Costa del Sol, among others. On the other hand, *political-administrative regions* –the Regional Autonomies- understood in this context as tourism "regions". The consideration of the Regional Autonomies is based on *two factors*:

- In general, due to the importance of the public administration as an agent that manages the tourist area.
- In particular, with regard to the theme of the effects of climate change on tourism, it will be, to a great extent, the public powers that have to take the decisions and implement the actions.

14.1.4. Impact of tourism on the economy

As has already been pointed out, international tourism contributed, in the year 2003, 36,800 million euros, which showed a growth of 3.7% compared to 2002. In global terms, the influence of tourism on the national economy is relevant, in aspects such as contribution to the Gross Domestic Product (GDP), to the creation of employment and to covering the commercial deficit in the Balance of Payments. The following are some data representing the importance of this aspect:

- The *contribution of tourism to the GDP* in 1999 amounted to 12%, with an increase of over one point in three years.
- The estimates of *tourism spending* amounts to a total of 77,500 million euros, of which approximately 50% comes from spending by Spaniards.
- Spending on tourism in Spain is basically concentrated on *accommodation and restaurants* with approximately 60% of the total.
- In the year 2003 revenue from tourism was 77.4% of the *cover of the trade deficit*.

With regard to employment, in the year 2002, the people paying social security corresponding to the subsectors of the tourism sector amounted to over 2 million *jobs* which is 12.5% of employment of all the sectors of the national economy. If we take into account that the dependence on tourism of the other economic sectors, i.e. agriculture, industry and, above all, services, is very great, we must conclude that, through these multiplying effects, a very significant part of Spain's economy is linked to the evolution of tourism.

Considering that, by definition, tourism involves moving from one place to another, the primordial role played by the *new information and communication technologies* is essential in order to connect a demand and an offer separated from each other in space. This same fact also involves significant temporal increases in population that needs to be supplied with a big amount of infrastructures and services, which makes it even more complicated for the sector to function, but which, in turn, contributes to creating revenue and employment in these activities.

Considering the predominance of "sun and sand" tourism, one can observe a *growing segmentation of the market,* which in relation to the effects of climate change is of great interest, due to the fact that the impact will affect one type of tourism more than another. If each type of tourism generates different spending capacities and different multiplying effects, it is essential to learn of the positioning and evolution of the different markets. At the same time, some zones or tourist destinations, mainly the traditional ones, depend almost exclusively on tourism for the development and evolution of their local economies, because the rest of the areas are subordinated to the inflow of tourists.

The importance of tourism in Spain's economy is limited to figures of a very general nature, like the aforementioned ones, which does not facilitate a detailed analysis of the influence of determined "*shocks*" in the sector as a whole and in the different subsectors it is composed of. Consequently, there is an increasingly urgent need to avail of economic and tourism indicators that go beyond data related to tourists, which would enable us to value better profitability according to types of products, countries of origin and destinations.

14.2. SENSITIVITY TO THE PRESENT CLIMATE

The influence of climate on tourism can be seen at *three levels*, because climate can act as a factor for locating tourism, as a resource of tourism and as a tourist attraction (Gómez Martín 2000, 2004d, 2004e):

- *Climate as a factor of location of tourism.* Climate is a geophysical or natural element of the geographic space considered as a factor for locating tourism, on intervening in the processes of functionality of a territory. That is to say, climate as an element of the geographic space is not neutral, but rather presents certain differential characteristics, which sometimes prevent, sometimes hinder and other times favour the establishment of tourism. In this sense, in Spain the creation of many of the existing tourist resorts has been governed by the desire to make the best of certain favourable local and regional climatic conditions (Gómez Martín 1999a, 2000, Vera Rebollo 1985).

- *Climate as a tourism resource.* Climate exists outside any considerations related to tourism, but it becomes a resource of tourism as soon as it is incorporated into a tourism commodity or service, these being promoted for consumption and used for commercial purposes through any channel of communication and marketing, always in order to satisfy the latent requirements of demand. Climate as a resource of tourism is considered to be fundamental when without it, it becomes difficult to develop and consolidate determined tourism activities in a territory (activities depending on climate and weather). Furthermore, climate is considered to be a complementary resource when it does not determine the tourism activity itself and becomes a subsidiary element of other resources (activities sensitive to climate and to weather). In Spain, it is the tourism activities and modalities depending on atmospheric conditions that generate the biggest flows of tourists (sun and sand, snow-based tourism, sailing...). In fact, many of the tourism products on offer incorporate this element as a basic input, that is to say, the natural environment, demonstrating the high potentiality of climate as a tourism resource (Gómez Martín 2000).

- *Climate as a tourist attraction.* Including climate in the tourism product goes further than simply considering it as "raw material" , as on many occasions it becomes an element capable of bringing quality into tourism: atmospheric conditions can help the tourists to carry out their activities in optimum conditions of enjoyment, safety and comfort. This is why climate often becomes an attraction factor, that is to say, an attribute or characteristic of the tourism product or destination which is decisive at the moment of purchase by the tourist. This is one of the reasons why climate is included in the pictures of the destination, and why it plays a key role in the promotion of tourism. Analysis of the verbal and iconic information on tourist brochures shows the constant direct and indirect reference to climate, confirming its role as an attraction factor (Gómez Martín 1999b, Olcina Cantos and Vera Rebollo 1998).

These and other theoretical facts related to the importance of climate as a factor of tourism location, resource and attraction are specified in certain specific aspects of the reality of Spanish tourism (Perry 1972, Mings 1978, Baretje and Crespo 1992, Smith 1993, Maddison 2001). Thus, the *main aspects of the relationship between climate and tourism* are (Gómez Martín 2000, 2004d, 2004e):

14.2.1. The climates of Spain affect the type of environmental framework in which tourism is to be developed, constituting in most cases spaces that are attractive and functional for tourism.

Thus, there is a high geographic concentration in the tourist destinations of the Mediterranean coast, which are highly specialised in tourism and sun leisure products, due to the optimum conditions therein for these activities (see Figures 14.1 and 14.2). A total of 55.3% of tourists residing abroad prefer the Regional Autonomies of Catalonia, Balearic Isles and Andalucia to spend their holidays. Likewise, 45.6% of Spaniards holiday in the Regional Autonomies of Andalucia, Valencia and Catalonia. The same occurs with the Canary Isles (20.6% of foreign tourists prefer this destination). In any case, there are *areas on the Mediterranean coast* (SE part) affected by certain extreme climatic characteristics that constitute *fragile systems*, often affected by conflicts and problems related to functionality (Perry 2003).

14.2.2. Climate has a great influence on the establishment of schedules for tourism activities.

In this sense, it must be pointed out that although the schedules of climate-tourism potentiality in most Spanish destinations present long and favourable periods which could affect *deseasonalisation* (Gómez Martín 2000, 2004a, Gómez Martín *et al*. 2002), there is great temporal concentration of demand at global scale. Thus, 48.8% of national trips are concentrated in the months of July, August and September (see Figure 14.3); 56% of the trips related to inbound tourism are concentrated in the months of June, July, August and September.

14.2.3. The weather affects activities related to tourism and their scheduling, especially if they are practised in the open air (De Freitas 2001).

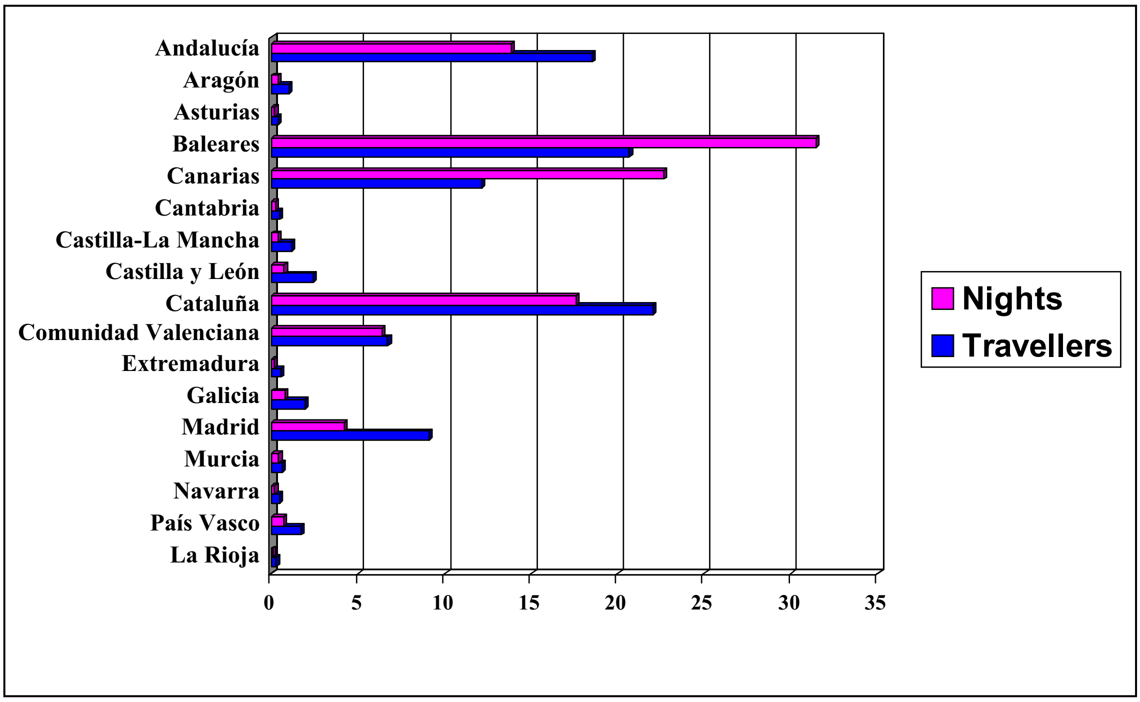

Fig. 14.1. *Distribution of foreign tourists in hotels according to regional autonomies (%) – 2003. Source: Own design based on data from the National Statistics Institute*

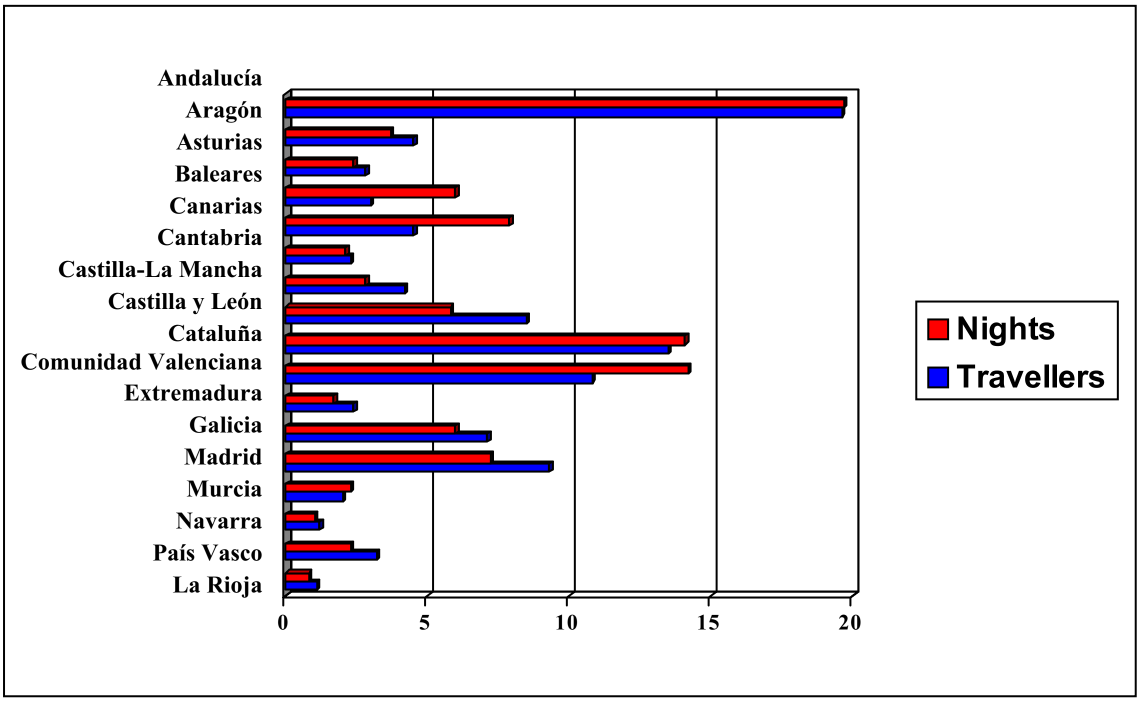

Fig. 14.2. *Distribution of spanish tourists in hotels according to regional autonomies (%) – 2003. Own design based on data from the National Statistics Institute*

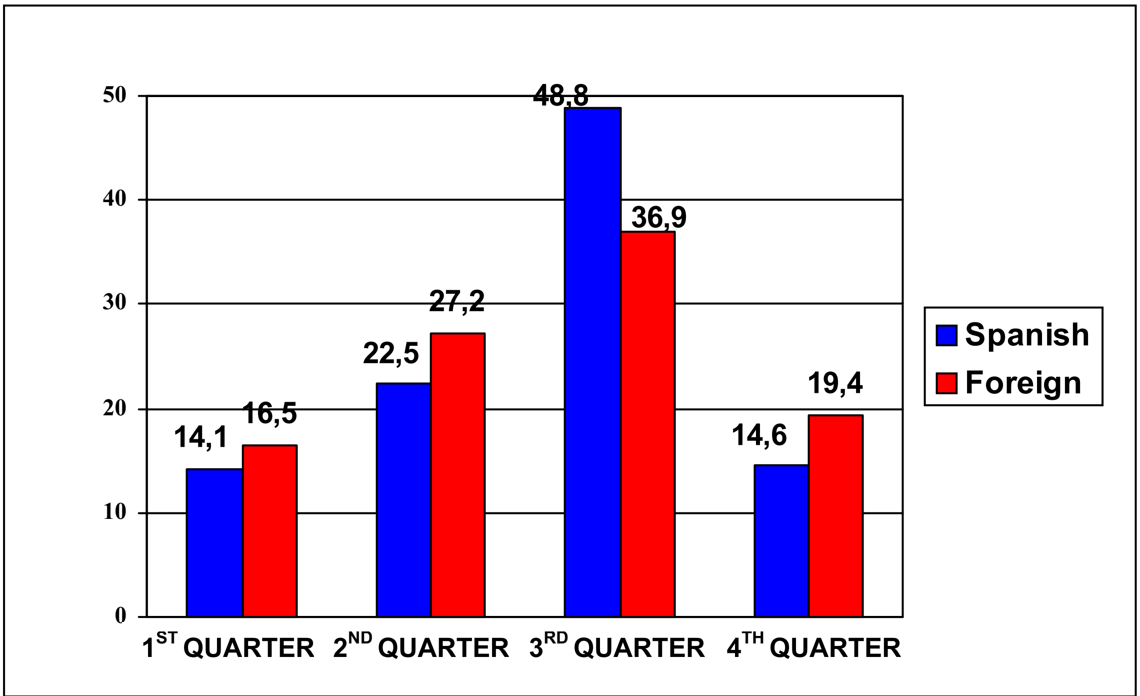

Fig. 14.3. *Distribution of foreign and spanish tourists per three-month period (%) – 2003. Source: Own design based on data from the Instituto de Estudios Turísticos (Tourism Studies Institute)*

14.2.4. Climatic and meteorological conditions affect the buildings and infrastructures of tourism

Not only climate and weather mean that a place will be frequented by tourists or not, but also how they are received and how much they enjoy their stay, the accommodation (in Spain, and especially in the Mediterranean sector, climate favours a variety of types of accommodation: from camp sites to other forms of accommodation less sensitive to the weather), the tourism architecture itself, the preparations that have been made and even urban design itself (Spanish town planners are aware of the importance of the beneficial effects of the suitable use of gardens and of certain elements of urban furniture – awnings, canopies, etc.- in fitting out outdoor spaces for tourism) (Gómez Martín 2004d, 2004e).

14.2.5. Climatic and meteorological conditions have a great influence on the functioning of transport and communications, facilitating and conditioning travel for tourists

14.2.6. Climatic and meteorological conditions affect the tourists' feeling of safety

In this sense it should be pointed out that *a high risk of climatic catastrophes and natural catastrophes in general is incompatible with any type of tourism activity.* In Spain, extreme events linked to climate must not be underrated and are an important factor to be considered in planning. In any case, observation shows that the risk and/or catastrophic nature of many episodes depends on the adequacy or inadequacy of human intervention in the geographic space (incorrect location of tourist infrastructures and facilities, especially in vulnerable points, like coastlines, riverbanks and mountain slopes) (Gómez Martín 2004a, 2004b, 2004c, Olcina Cantos 1994).

14.2.7. Climatic and meteorological characteristics make up the environmental conditions and affect the tourists' perception of enjoyment and comfort (feeling of wellbeing), as well as their health

Under normal conditions, the climates affecting the peninsula and the islands constitute healthy and comfortable environments for tourists. In any case, the Mediterranean and the inland part of the peninsula are occasionally affected by extreme episodes during the holiday period (in particular, heat waves) which alter the conditions of comfort, affecting in the short and medium term the frequency of visits by tourists.

14.2.8. The climatic and meteorological conditions of an area are often offered as a tourist attraction

Although each tourist activity requires its own climatic and meteorological conditions, these being a factor that attracts tourists, these seem to have a particular taste for sunshine and relatively high temperatures (environmental comfort): most of them like to carry out their activities (whatever these may be) in places characterised by mild temperatures and a lot of sunshine: So for British tourists, for instance, the fundamental factor in the choice of Spain as a destination is the climate, especially among those who say they have come on holidays. The same thing happens with tourists from other countries. These same preferences can also be observed according to modalities of tourism (Gómez Martín 2000).

Most Spanish tour operators, aware of these preferences by the tourists, incorporate climate as an attraction into the image of the product, because they know that this can affect the buyer when choosing his destination. So, for example, inspection of Spanish tourism brochures shows a noteworthy presence of atmospheric elements both in the iconic information (logotypes, photographs and illustrations) and in the verbal information (text, statistical tables, slogans and headlines) contained therein (Gómez Martín 1999a, 1999b).

14.2.9. Climatic and meteorological conditions affect the tourists' degree of satisfaction

Certain climatic and meteorological conditions that allow the tourist to carry out his activities with a high degree of safety, comfort and enjoyment contribute to satisfying his initial requirements, and therefore, to raising his degree of satisfaction. Thus, for example, we can see that in the study by the Secretaría General de Turismo (tourism dept.) *Degree of satisfaction of demand by national and foreign tourists in relation to the Spanish tourism product (1991)*, "sun and climate" are among the elements that most impressed the tourists due to satisfying their needs: 89% of answers by Spanish tourists showed a good or very good impression of the climate-weather recorded (a very high score in the scale of satisfaction); among the foreign tourists, this score rose to 93.1%. In any case, the results of surveys throughout the years are subject to the whims of nature (Gómez Martín 1999b, 2004d, 2004e).

14.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

14.3.1. Climate change and the tourism system

The relationship between elements of the weather and tourism have traditionally been approached within a framework of natural variability, because it was considered that climate was a special natural tourism resource among natural tourism resources, due to being renewable and non-degradable. However, the publication in 2001 of the Third Evaluation Report by the IPCC (International Group of Experts on Climate Change) has shown and confirmed that *atmospheric resources are also subject to modifications* resulting from certain human activities. This recognition of climate change due to anthropic causes has led the traditional climate-tourism relationship to be reconsidered, but now within a context of change and uncertainty (Gómez Martín 2004e).

Considering that the *tourism system* is made up of four fundamental elements (the geographic – tourism area, demand for tourism, offer of tourism, and the market operators), it is logical to think that they can all be altered, directly or indirectly, by the phenomenon of climatic change. It can therefore be expected that the first element to be affected by this phenomenon will be the geographical-tourism space itself, and consequently, and in this order, demand, offer, and the market operators. In any case, this logical sequence can be altered to respond to climatic change, without casting any doubt upon the tourism sector. It is clear that the Spanish tourism system has proven its capacity for adaptation: it is *a dynamic system capable of generating responses,* and more so if we consider that in this case the change is slow and therefore allows for planning and intervention in time in relation to the different elements of the system in order to counteract any possible derivative effects (Gómez Martín 2004e). However, the degree of degradation that can be seen in certain traditional tourist destinations shows little margin for manoeuvre and any change could worsen even more the current conditions, which are already out of balance.

14.3.2. Repercussions in the geographical-tourism area

Climate is a natural or geophysical element forming part of the geographic-tourism space. Any modification thereof could generate changes in the rest of the geophysical or geo-human elements making up this variable of the tourism system, changing an initially attractive and efficient space into a space lacking in resources, attractiveness and functionality.

Climate change is expected to cause *reduced rainfall* (even more serious in the south of the peninsula) and *increases in its inter-annual variability*. Likewise, *temperatures will foreseeably rise,* especially in summer, and it is more likely that there will be more *extreme climatic events.* These changes may generate a series of *repercussions in the geographic-tourism area,* because:

- Alterations may be caused (significant changes in regional limits or degradation-disappearance) in some of the *ecosystems* characterised by a high number of ecological habitats and an appreciably high percentage of world biological diversity. These natural spaces distributed throughout the peninsula and the islands, traditionally considered as attractive spaces from the tourism point of view, may suffer alterations with regard to ecological and aesthetic qualities, fragility and in general, tourism-recreational values, *ceasing to provide social, economic and environmental benefits.*

- Changes can occur in the *global hydrological cycle*, generating serious impacts on the regional and temporal distribution and availability of water. The decreased water reserves may lead to problems economic functionality or feasibility in many current tourist sites, especially those located on the Mediterranean coast and in the Balearic and Canary Isles.

- Notable changes may occur in the areas currently dedicated to *winter tourism.* The complexes situated below 2,000 metres may disappear or reconvert to other tourism modalities (although this limit may vary latitudinally), due to the disappearance or scarcity of the snow resource. The ski resorts will be forced upwards in altitude and they will have to increase investment in cannons for the production of artificial snow. In any case, the irregularity of snowfall and the decreased temperature resulting from the delay in the appearance of the snow layer and the premature worsening of the quality of this in springtime, do not guarantee the profitability of investments in determined geographic areas.

- In inland and coastal areas, changes may be generated in the *activities scheduled* due to worsened climate-tourism conditions in the mid-months of summer due to excessive heat and an increase in the potentiality of the inter-seasons (spring and autumn). Something similar could happen in determined mountain areas, although in the opposite sense: the shortened winter season due to a lack of snow might be compensated by the lengthening of the summer season.

Global climatic change will foreseeably cause an *increase in sea level* in the next few decades, due to the thermal expansion of the water in the oceans and to the melting of glaciers and of the polar ice caps. This rise in sea level may have *notable consequences for Spanish coastal tourist resorts*, because:

- It may threaten their existence or *present location.* In particular, the low coastal zones of the Mediterranean Coast and the Gulf of Cadiz may be affected.
- With an increase in erosion processes, all the coastal frontline *infrastructures* may be altered (beaches, seaside boulevards, docks, piers, marinas, among others).
- There may be adverse effects for the *freshwater reserves* available in the coastal wetlands and aquifers due to the intrusion of salt water, exacerbating a situation which is already critical, due to the water supply problems in certain tourist resorts.

In short, the impacts on the geographic-tourism space will not be homogenous and their effects will be worse in the more degraded areas, with big imbalances and a greater conjunction of climatic effects.

14.3.3. Repercussion for tourism demand

The sensitivity of tourism to climatic conditions can be seen in *two different ways* from the point of view of demand:

- *Directly,* because climate is a factor of primary motivation for mass leisure tourism, especially in the two main elements of the decision-taking processes in relation to vacations: destination and time of year.

- *Indirectly,* because climatic conditions are part of the environmental context of tourism. Thus, any alteration of the natural environment constituting the basis of the tourist attraction will affect the activities it sustains, such as the conditions of the beaches and coasts, the mountains, the natural and urban areas.

From the point of view of demand, the influx of tourism into Spain, as we have already pointed out (see section 14.1.2), comes from abroad and from within the country, and the repercussions of climate change in tourism can also be seen in a differential way.

International inbound flows come mainly from the countries of Northern Europe, basically Britain and Germany, which jointly total 49.6% of foreign tourists coming to Spain. The basic motivation of these tourists is to find warmer climatic conditions than in their own countries. This motivation is through comparison, and they seek higher temperatures and less rain and adverse conditions in order to do outdoor activities that they do not usually enjoy in their own countries (Perry 2001). Besides, Spain is a friendly country, safe and easily accessible, where, for example, it is not necessary to be vaccinated against exotic or tropical diseases.

If these comparable climatic conditions change, without any corrective measures being taken, several *effects on the demand for international tourism* can occur, if we consider that the tendencies contemplated involve the transformations of the tourism space mentioned in the previous section:

- *Decrease in summer holiday travel* to zones of the Spanish Mediterranean coast due to the loss of attractiveness of certain coastal tourist destinations, due to excessive temperatures in the summer season.
- *Increased travel in the country of origin*, because the tourists from Northern Europe will find within their own geographic area warmer conditions, encouraging them to holiday in their own countries.
- *Increased travel in spring and autumn* to destinations in Eastern and Southern Spain, reducing the strong seasonal influence seen in the summer months, because with the more moderate inter-season temperatures the coastal areas would be more attractive for this type of travel.
- *Increased travel by foreigners to the coasts of Northern Spain* due to the fact that the climatic conditions of these destinations would make them more attractive for tourists.
- *Increases in the length of the visit of certain segments* such as the elderly, who have more available time and who are becoming the majority tourists in certain destination due to the progressive ageing of the population of Europe. These can lengthen their stay in the coastal destinations, and even buy holiday homes in these tourist areas and come to stay permanently.

The *national tourism demand* has certain characteristics which are somewhat different from those of the foreign tourist. Those referring to motivation, seasonality and geographic concentration in Mediterranean coastal destinations follow similar criteria to the rest of the European countries, although less intensely. Thus, the diversification of the national demand leads Spaniards to visit inland destinations with a greater natural or cultural attraction, compared to the type of travel preferred by foreigners. Furthermore, we must consider that over

90% of trips made by Spanish tourists are made within their own country, and that changes in *climatic conditions are better accepted by the national tourist in his own country* **,** except for those owing to natural catastrophes or extreme events (flooding, forest fires), which have an almost immediate effect on demand. Besides, the big amount of second residences provoke other types of relationships with the social and natural environment.

Consequently, the possible repercussions for national internal demand are the following:

- *Progressive fragmentation of travel***,** with a reduction of the number of days of the average stay in the destinations, due to the high summer temperatures associated with the sun and sand type trip.
- *Increased flows of tourists to the northern coasts* which could experience an improvement in climatic conditions (higher temperatures and less rainy days), which would favour bathing an outdoor activities, although the conditions of the sea, with regard to use, are different, due to their inherent characteristics (waves, wind, currents).
- *More travel to inland areas* with other attractions associated with nature, the rural world and culture.
- *Less travel to the nature areas* due to deterioration by climate impacts.
- *Shortened snow tourism season* due to less snow cover especially at lower altitudes.
- *Increased travel to Northern European countries* which would gain in attractiveness in summer months, with a softening of temperatures in these areas and notable temperature increases at home.

Although the effects on demand have only been considered in physical terms, the consequences for monetary variables (revenue, expenditure) would be in consonance with those described for travel. Thus, areas where wellbeing is less perceived would attract tourists with less purchasing power.

It must be remembered that tourism is a human and discretionary activity (Parry 2000) and the tourist expects to find favourable conditions that will provide him with a sense of wellbeing and a satisfactory experience. For both national and international tourism, therefore, the demand that is most affected is that associated with leisure and holiday tourism (the majority one in our country), whereas other types of tourist, like for work, visits to family and friends, health, studies or sports, would be less influenced by climate and its possible changes.

An important aspect of possible change in the behaviour of demand is the degree of *influence of weather forecasts* transmitted through the mass media. This information usually has a direct and immediate effect on decision-taking by tourists and is often generalist with little local accuracy, to the detriment of determined tourist destinations and seasons when the forecasts are not very favourable.

14.3.4. Repercussions for the tourism demand

The third level of climate change impact on tourism, after geographic space and demand, comprises the components of the tourism offer, mainly the tour operators.

Changes in demand flows are usually due to transformations in the preferences and desires seen mainly in differentiated types of behaviour. These will also involve modifications in the providers of services in a direct way, like *accommodation establishments and travel agencies.* However, we must point out the strength of the tourism industry, the future tendency of which will foreseeably be towards growth, because the main structural elements of its evolution, revenue and leisure time, can continue to develop favourably.

Tourism is an activity with great capacity to *resist crises* and with much *capacity to redistribute.* This means that the flows of tourists from one place to another could still continue to generate average profit levels similar to those obtained to date. The most negative and direct impact could affect the companies situated in the most vulnerable destinations, with serious economic consequences, mainly for those who depend on big investments in infrastructures. But, at the same time, the tendencies considered in relation demand allow these companies to extend their activities to other time periods, thanks to the lengthening of the season to the spring and summer months.

Other companies, like the *tour operators and travel agencies at the point of origin* would hardly suffer these impacts in economic terms, because their capacity to adapt is much greater and changes in demand would enable them to make other changes in destinations and other periods of higher intensity and better financial conditions.

The main repercussion at the global level of the offer and, consequently, for the Spanish economy as a whole, is the smaller amount of foreign tourists coming in, because they prefer to stay at home, which would lead to *lower revenue from tourism* at global level and in the more vulnerable zones, a risk for the stability of their local economies. However small or slow the changes may be, their effects in areas which are already suffering from serious imbalances could lead in the medium and long term to big changes in their economic situations and, in the worst scenarios, the progressive closure of their tourism and non-tourism establishments, increased unemployment and bankruptcy in the destinations.

14.3.5. Changes in action by the system's agents

Tourism is a system in a continuos state of adaptation, responding to demographic change and to new demands and technologies. Climate change may present new challenges and opportunities for investment in tourism, allowing the new environmental conditions to be capitalised (Parry 2000). In this sense, the *public and private agents* acting in the system, mainly in traditional tourist destinations, can orient their actions in different directions:

- *Incorporating travel incentives* into their zones, with more tourist attractions combined with cultural and sports activities.
- *Maintaining the value of the lure of the coastal areas*, displacing future tourist complexes inland, although nearby.
- *Promoting less rigid infrastructures* favouring the expansion of the coastal areas and their long-term sustainability.
- *Improving the conditions of wellbeing* during the tourists' stay, installing air conditioning in all accommodation.
- *Designing Innovative development conditions* for the existing tourism offer with new products or modifying the existing ones.

The changes would have more influence in those areas most economically dependent on tourism, and, according to the aforementioned tendencies of demand and offer, they could have more affect in the regions most subordinated to demand flows from abroad (see Figure 14.4). By way of an example, around 34% of package tours abroad for inhabitants of the United Kingdom are to Spain, mainly to the Balearic and Canary Isles (Viner and Agnew 1999). The economic level or institutional resources of a community or region condition its capacity to adapt.

The agents can opt to make functional changes in the destinations in order to balance human activity and environmental conditions. However, the consequences of climate change can also lead to a change in the *interests of the agents* towards activities that take advantage of the new opportunities offered by the new scenarios, like the enlargement towards inland areas, in order to progressively relieve the pressure in the more vulnerable areas, which also tend to be the most saturated and fragile ones, and whose future sustainability was already threatened, without considering the effects of climate change (for instance, rural tourism nearby the coast).

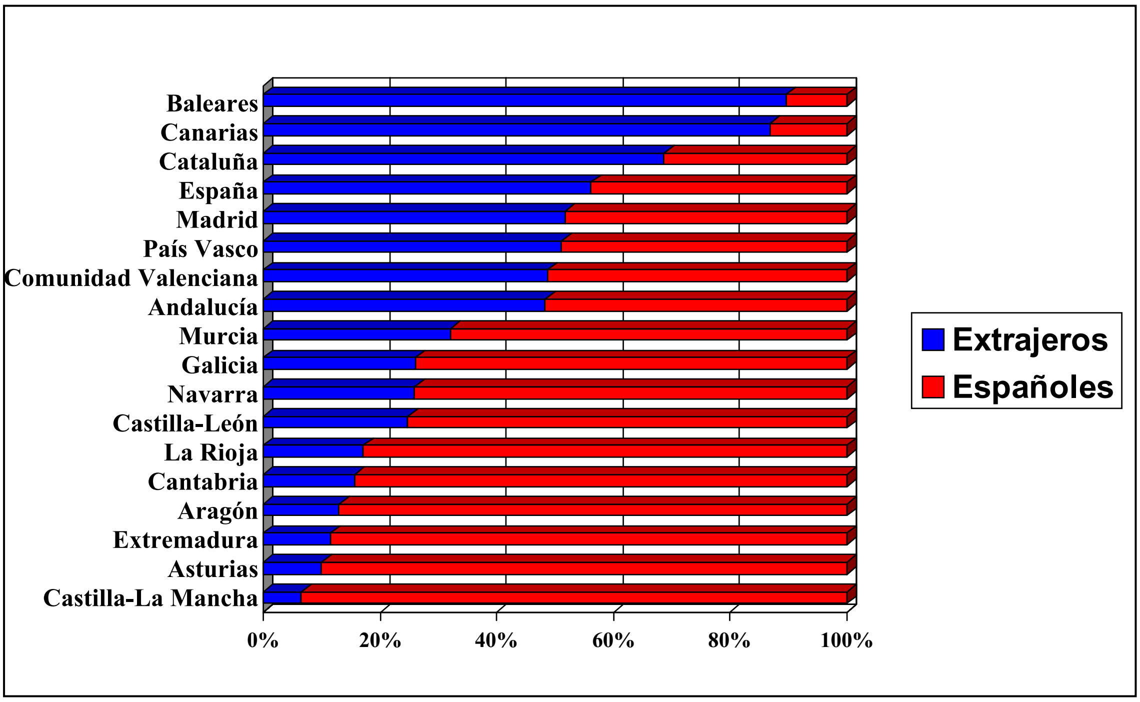

Fig. 14.4. *Distribution of tourists according to regional autonomies (%) – 2003 (blue: foreigners; red: spanish) Source: Own design based on data from the Instituto de Estudios Turísticos (Tourism Studies Institute).*

The *strategies* that the agents in the tourism system could develop will depend on the objectives set, which can be very different according to zones, the level of repercussion, the intensity of the changes in demand and the social and economic conditions of the destinations. The increasingly generalised tendency towards sustainability involves accepting slower growth rates, compensating for this by higher quality facilities and services provided, and the progressive disassociation of the destination from the exclusive sun and sand image.

14.4. MOST VULNERABLE AREAS

14.4.1. Zoning of tourism in Spain and vulnerability

In Spain, the impact of climatic change could affect in an unequal manner the different types of tourism and the different geo-tourism zones. Our country has a great diversity of resources, products and tourist destinations, which in turn present a very contrasted degree of relationship or association with climate in each case. In view of the preliminary nature of this report, the scale of analysis we are operating at and the objective –the identification of most vulnerable zones- , we have detected as the most vulnerable zones and products, those associated with the coastal and mountain environments. Specifically, it is *sun and sand tourism*, which has shaped the tourism function on much of the Spanish coast, and *snow-based tourism* (ski and mountain resorts) that has become the most emblematic type of tourism in mountain areas, and, in certain cases, the most important one.

The fact that the coast and the mountains are the tourist resorts most vulnerable to the impact of climate change is not a reality particular to Spain, and worldwide, it has been detected that sun and sand tourism and snow tourism might be the most affected by the predicted scenario of climate change. Indeed, the World Tourism Organisation, when it organised the *1st International on Climate Change and Tourism* (Djerba, Túnez, 9-11 of April, 2003), focussed the theme and the debates on the effects of climate change in three territorial environments: the coastal areas and islands, mountain regions and the areas exposed to drought or flooding.

14.4.2. Coastal areas and products

The geographic condition of the *coastal space* (maritime dynamics and coastal morphology), the model of territorial organisation and, in particular, the model of tourism development, are the factors determining the greater or lesser degree of the predicted climate change. In a country whose activities are increasingly more involved with the seaside, as opposed to former times, the *natural vulnerability of the coast is increasing as a result of the high degree of artificialisation.* Furthermore, given the diversity of the Spanish coast, and its unequal tourism potential and development, fundamentally sun and sand tourism, the premise is that the impact of climatic change will be different in each coastal zone.

In relation to *regional contrasts*, the description of the coastal areas in Spain distinguishes the Mediterranean and island coasts from the Atlantic and Cantabrian (northern) coasts. Spain has beaches of all types and conditions and very varied climates and waters. Over 80% of international tourists visiting Spain goes to its beaches: Mediterranean, North Atlantic, South Atlantic and the Canary Isles (with a subtropical climate). Depending on their climates, attributes and the time of year –clearly related to climatic cause-effect- Spanish beaches present a higher or lower level of adequacy for tourism. Taking the season of the year as a reference, it could be said that there are beaches that are used throughout the whole year. These are the ones on the southern Mediterranean coast and on the Canary Isles. The summer beaches, and, to a great extent, the spring and autumn ones, are on the northern Mediterranean coast and the Balearic Isles. And, lastly, the summer beaches are those of *Green Spain,* that is to say, Galicia, Asturias, Cantabria and the Basque Country. In the scenario of climate change, the impact will undoubtedly be different and following a variation in climatic conditions, the “right time of year” for the beaches, in relation to comfort, will also be modified, which will give rise to new positive or negative situations and, in any case, to the *need for adaptational strategies.*

The *northern and central Mediterranean* encompasses the coasts of Catalonia, Valencia and Murcia. Three sectors are distinguished, shaped by concave arches, the result of the settling of the coast. The first sector, between Cabo de Gata and Cabo de Palos in Murcia, present a morphology with a predominance of rocky, broken coastline. The second sector, between Palos and Cabo de la Nao, in Alicante, corresponds to a very varied coastline, from low and sandy to high and abrupt. Finally, the third sector, from Cabo de La Nao to cabo de Creus in Girona, presents an alternation from high and rocky to low, sandy coastline.

The coastline of Andalucia stretches along the southern Mediterranean and the southern Atlantic, and two sectors can be distinguished here: the first, between Punta de Tarifa and Cabo de Gata, is characterised by being generally rocky and with cliffs, although some low sectors open onto sandy beaches; the second, from Tarifa to the mouth of the river Guadiana, is a low, mostly sandy coastline. With regard to the archipelagos, both the Balearic and the Canary Isles present very variable coastlines, climate being the differential factor of the environmental conditions in these tourist destinations.

The *North Atlantic and the Cantabrian* coasts offer a diversity of tourist activities and in this region, sun and sand tourism is generally not hegemonic, and in spite of being mostly based on sun and sand, it is still very far from the typical model of Mediterranean tourism. The Cantabrian coast is a straight line with very few recesses or projections and a rough sea. There are very few beaches, although the ones that do exist are very attractive and with fine sand, the result of the action of the Cantabrian sea. Thus, high and rocky coastline predominates, mainly due to the proximity of the Cordillera Cantábrica mountains. The coasts of Galicia present a different physical space: a high, abrupt coastline with successive cliffs and with geographically particular areas. A unique landscape of great value for tourism, made up of creeks that vertebrate this extraordinary coast, with long inlets that break up the cliff coastline and allow for the establishment of population nuclei, protected from the permanent fury of the ocean.

In short, *very varied morphology and coastal dynamics*, which will be *affected in different ways* by the forseeable climate change, whether by the alteration of climatic conditions or by a rise in sea level and marine dynamics. In this case, the Mediterranean Coast and Gulf of Cadiz sectors would be affected.

The effects of the foreseeable climate change on coastal tourism could cause a *displacement of seasons* due to the intensification of the hot and dry summer period, but, on the other hand, the favourable effect of enlargement and *deseasonalistion* of this period is predicted. Consequently, the holiday period may be lengthened. There may also be a greater frequency of atypical periods, due to excessive heat out of season and, although it may seem contradictory, sporadic fresh and changeable summers. The summers will get hotter to the point that the sun will become an uncomfortable factor, and being too hot, Spain may lose its lure and its comparative advantage with other destinations. Very hot weather is predicted for southern Europe, perhaps too hot to go on holiday, but this condition is also predicted for Spain's competing destinations. Consequently, the long-term forecast is that the countries in the Mediterranean basin, -including Spain- will become tourist destinations mainly for spring and autumn.

An appraisal of this foreseeable scenario, however, allows us to reject the alarmism and the catastrophic bases of certain hypotheses. A temperature increase would not have serious consequences for Spain, because the change in climatic conditions on the coast could have a *deseasonalisation effect*, as we have already pointed out, as it is possible and predictable that the tourist will enjoy bathing in the sea from May to October. It is also possible that mass tourism will decrease in the months of July and August, not only due to the increase in temperatures, but also because people are tending to distribute their holidays throughout different periods, which has nothing at all to do with climatic change.

The change in climatic conditions, in the direction predicted, could also involve *new opportunities for the development of sun and sand tourism*, with new demand segments. This might involve seeking and developing destinations with pleasant summer temperatures, like, for instance, Northern Spain (Cantabrian coast) and the mountain areas. Other opportunities will also arise for others scopes of business related to tourism, such as an increase in visits to protected natural spaces, or through the revaluation of the destinations dedicated to nautical or inland sports and activities on the rivers.

Activities related to tourism depend directly on the quality and availability of the resources used, whether these be renewable or not, as well as factors related to offer, infrastructure and services, among other. This is why environmental degradation is directly associated to the loss of attractiveness, and therefore, to the cessation of the tourism activity, due to the impossibility of continuing under these circumstances. In the case of the foreseeable climate change, the Spanish coastal destinations would be affected by the change in environmental conditions and, as a result of this, adaptational strategies would need to be planned. Society would have to deal with the physical deterioration of the coast, investing in works to protect, renovate or rebuild the seafront, or opt to rationalise the human occupation of the coastal areas.

The change in scenario does not only involve an alteration of the conditions of resources for tourism, but also a modification of the availability of, and competition for, the *inputs* into the tourism system and, in particular, *the water supply*. This problem already exists in certain areas due to the concentration of the tourism demand in time and space. In order to satisfy the demands, the system will have to resort to the desalinistion of sea water, the use of subterranean resources (which in many cases has led to the overexploitation and salinisation of coastal aquifers, which is practically irreversible), and the construction of new dams or water transfer systems. The solution to the water problem is clearly one of the key factors for the maintenance of much of the tourism industry on Spanish coasts, particularly in the possible scenario of climate change.

The theme of climate change and its impact on the tourism sector is happening at a time in which tourism is undergoing certain changes in supply and demand at a rate unknown to date, to the extent that some analysts consider it to be a *change in the tourism paradigm*. This reference is of interest because the alterations experienced by tourism in the future could be caused by the impact of climate change and if this occurs, they will be projected onto the modification that are already underway, onto the new tendencies of supply and demand: the change in destinations, the appearance of other competitive destinations, traditional sun and sand ones, others far away and others of a different type competing with sun and sand (urban, nature, culture, among others). To a certain extent, the theme related to the foreseeable loss of attractiveness by Spanish destinations must also be dealt with in comparative terms, that is, it must be understood that climatic change will also affect other destinations, both from the same business segment (sun and sand, destinations both nearby and far away) and of other products.

By way of a conclusion to the analysis of this foreseeable situation, it is vital that we implement *converging strategies* in order to provide adaptational actions both at national level and at particular destinations, according to their state of evolution and their existing degree of deterioration, as it is not the same acting in unsaturated geographical parts of the coast as in areas which currently suffer from serious imbalances.

14.4.3. Mountain zones and products

In winter tourism (snow tourism – ski resorts), the consequences of climate change are now more evident than in the case of sun and sand tourism, and the difficulty involved in adapting it is also more patent. Thus, it is generally agreed that the mountain areas affected can be seen to be more vulnerable than the coasts and the islands.

Knowledge of the *snow layer and its annual renovation*, as well as of the potentially skiable domains, is quite accurate at the present time, even from the point of view of the conditions it offers related to commercial exploitation and economic viability. The different mountain massifs present a *high level of diversity*, both in comparative terms and with regard to their own internal composition, and this diversity depends, in each case, on the respective northern or southern latitudinal location and on altitude, parameters which will determine their environmental conditions in general, and in particular, the snowfall regime, with the resulting availability or non-availability of the snow resource. For example, in the Pyrenees, a great deal of the precipitation in the winter months consists of snow and there are many places and zones that register between 20 and 30 days of snow a year, with notable thicknesses and a permanence of several months. Snowfalls becomes significant in many parts of the Catalonian Pyrenees above the elevation of 1,500 m. But above 1,800 m, the snow layers, which over 15 cm. Between December and April, are more interesting and favourable from the commercial point of view (López Palomeque 1997).

The snowfall regime is characterised by *temporal* (seasonal and inter-annual) *and spatial* (altitudinal and latitudinal grading of Spanish mountains) *irregularity* which in turn causes irregularity in the snow business. This regime gives rise to cyclical situations encompassing very bad periods with hardly any snow to others with abundant snow, thanks to generous meteorology. Wind, fog and high temperatures have a negative effect on the permanence of the snow. Besides, we have to take into account the commercial structure of the resort and the capacity of its technical services, a basic factor for the maintenance of the snow layer (machines, signposting).

The irregularity of the snow has led to the adoption of strategies for the production of this natural resource through *the manufacture of snow* (produced snow), the installation of “snow cannons”, which has been habitual practice in all resorts since in 1985 La Molina (Girona) installed the first cannons. In the 2002/2003 season, there were 3,319 cannons. In short, the resorts have been forced to install snow cannons in order to guarantee the practice of skiing, by overcoming climatological conditions. Furthermore, given the need for all of this, and the costs and pressure of the investments made, the public administration has lent a hand to the sector with different lines of grants (snow insurance, investments in snow cannons, promotion, machinery) (Gómez Martín and López Palomeque 2003).

Spain has *29 alpine ski resorts*, 13 of which, in turn, have ski runs for cross-country skiing, and 15 resorts exclusively for cross-country skiing. Spanish ski resorts have a total of 344 mechanical lifts, with 7 cable cars, 136 chair lifts and 201 teleskis, with a transport capacity for 356,671 people/hour. These 29 alpine ski offer a total of 822 ski runs totalling 864 linear skiable kilometres and *Halp-Pipe* and *Snowpark* km. for the practice of snowboard. With regard to cross-country ski, a total of almost 400 km. of ski runs was on offer for the 2002/2003 season. Practically all of the most important Spanish mountain ranges have ski resorts: *the Macizo Galaico* massif (Manzaneda resort); the Cordillera Cantábrica (Alto Campoo, Valgrande-Pajares, San Isidro, Leitariegos); the *Sistema Ibérico* range (Valdezcaray, Valdelinares, Javalambre); Aragón Pyrenees (Astún, Candanchú, Formigal, Panticosa-Los Lagos, Cerler); Catalonian Pyrenees (Baqueira Beret, Boí Taüll, La Tuca, Espot Esquí, Tavascan, Llessui, Port Ainé, Port del Comte, Rasos de Peguera, La Molina, Masella, Vall de Núria, Vallter 2000); the *Sistema Central* range (Navacerrada, Valcotos, Valdesquí, La Pinilla, La Covatilla) and the *Sistema Penibético* range (Sierra Nevada). The maximum elevations of the resorts are at around 2,500 metres and the minimum elevations at around 1,500-1,800 metres, with the exception of Sierra Nevada (2.550-3.280 m.), the southernmost one.

In spite of the irregularity and the limitation of the snow and of the vulnerability of the snow business, the mountain and snow sector in Spain has been growing in the last few years in relation to its two basic components: demand and supply. Winter tourism in Spain, however, presents certain structural contradictions which generate malfunctions that will be exacerbated by the impact of climate change, although these will vary according to the mountain range: irregularity of the snow resource and insecurity in the snow business, dependence on the environment, automated production of snow within a context of difficult ecological balance, under the auspices of the public administration.

There are two types of evidence of the impact of climate change on winter tourism. On one hand, *the scientific evidence*, the different studies showing the slight increase in mountain temperatures, the lower average thickness of the snow and the greater temporal and territorial irregularity of snowfall. In Spanish mountains, there is a tendency to decline of precipitation in the form of snow and a tendency of temperatures to rise (particularly in February and March). An observable effect supporting these new parameters is the reduction of the Pyrenees glaciers – half of them have melted since half-way through the eighties- and the increased elevations of the snow layer. If these tendencies continue, there will be increasingly less snow at lower elevations. Furthermore, *the empirical evidence* backs the scientific knowledge. This involves the perception of change by veteran skiers who state that the snow elevation has risen, that there is now less snow at lower altitudes. Certain businessmen and resort managers also share this opinion, to the extent that they have made big investments in the production of artificial snow the long-term profitability if which is uncertain, and this is one of the biggest worries in the sector.

The predicted climate change will not mean the end of skiing, because the resorts at higher altitudes can survive as *winter tourism resorts*, whereas reduced snowfall will have serious economic consequences in the valleys that earn their living from skiing and a big ecological impact in the high mountain. It is predicted that, as the ski resorts start having problems at lower elevations, and as they abandon the skiing offer, the pressure will increase in ecologically more sensitive high-mountain areas. The viability of the resorts at lower altitudes will initially depend on the artificial snow cannons. But in the long term, the temperature increase will make the production of snow increasingly inefficient and costly (Scott *et al*. 2001).

The *adaptation strategies* for adjustment to the impact of climate change contemplate the intensification of the artificial snow, which is very well developed and which ahs a fragile ecological balance due to the fact that it has been a strategy for the last two decades for dealing with the temporal and spatial irregularity of snowfall. This strategy could benefit from technological advances (high-tech cannons that make the manufacture of snow possible at higher temperatures, about 2 degrees higher than before), but the intensification of this system clashes with the principle of economic sustainability and environmental sustainability.

However, this strategy would only solve the problem partially, and therefore, the ski resorts *would tend to become mountain resorts* (with diverse products), losing the specific nature of the original, exclusive product; the snow. This could be maintained to a lesser degree, at higher elevations, through artificial production, but it would be very costly, and at odds with the principle of environmental sustainability. The ski resorts would be transformed, ceasing to be purely winter resorts, becoming instead “tourist resorts” –on occasions in the classical sense of the term *resort*- with a variety of products on offer throughout the year, particularly in summer, with demand from tourists who dislike the beach destinations. The *deseasonalisation* of the activities of these centres is now a reality and will continue to be so in the future. This process would involve, on one hand, a strategy for optimising the facilities and the business management itself, widening the range of products with new business opportunities, and within the framework of this Report, an adaptational process imposed by the impact of climatic change.

Considering this forecast, *two needs* are imposed:

- The *planning of the development projects* and of initiatives for new resorts, avoiding the construction of infrastructures which in the medium term could become obsolete as a result of climate change.
- The need *to manage in a responsible way* the remaining resources (landscape, monument heritage), increasing the value of these as tourism resources, as they were only of a complementary or secondary nature until now, related to winter tourism, but in the future, these resources may become an alternative, replacing the snow as the main attraction of the ski resorts, reconverted into mountain resorts.

14.5. MAIN ADAPTATIONAL OPTIONS

As can be seen in the previous epigraphs, Spain, is a leader in tourism, occupying first place with regard to sun and sand tourism, and if climate change affects tourism, especially the sun and sand modality, our country will foreseeably be affected by this phenomenon, with serious consequences.

Sun and sand tourism in Spain is a mature product, especially on the Mediterranean, and it will continue to be demanded, because enjoying a good climate close to the sea and fleeing from cold, unsettled weather is still one of the main motivators for tourists from Northern and Central. Consequently, the decisions taken by tourists as consumers of products, along with business decisions and strategies, may be subjected to certain modifications as a consequence of the sensitivity to the predicted climate changes. It is also likely that there will be a process of readaptation of the tourism subsectors and of the ones depending on these, in which some lose importance, possibly in favour of others.

These changes will not only occur within the scope of sun and sand tourism, but also in *other products*, like ski tourism and even determined types of rural and nature tourism which could be subjected to extreme circumstances caused by climate changes of a tropical nature, infrequent to date in Mediterranean countries. As a result, changes in decision-taking strategies will go beyond what is referred to as sun and sand tourism.

14.5.1. Adaptational options in relation to demand

One of the integrating elements of the tourism systems which will most suffer the impact of climate change is the demand for tourism. The first change that demand may show in its adaptational evolution towards the conditions of the natural environment are focussed on the *modification of behaviour by the tourists*, because their tastes, desires and needs will vary according to their appraisal of the destinations, their perception of the conditions in which the new products are offered or the existing ones are modified, and their expectations of having a satisfactory experience on their holiday. Some possible *adaptational reactions of demand* are:

- Climatic change may accelerate the tendency that has existed since the last decade of the last century towards a *reduction by the tourists of the average stay* in sun and sand destinations. In any case, at other times of the year the tourist might repeat visits to destinations of rural or urban tourism, among others. Since around one decade ago, we have been seeing the dangers of excessive sunbathing without protection. Although it is true that the sun and sand destinations based on a sunny environment and good weather are gaining ground over pure sunbathing, these health hazards, along with higher levels of insolation due to climate change may lead the tourists to reduce the duration of their stay, reinforcing the aforementioned tendency, initiated years ago, for other different reasons.

- Another aspect refers to the likely change that will occur at the *moment of decision-taking*. Good climate is a basic characteristic of the sun and sand destinations and an important one for people travelling to the Mediterranean for other reasons. The tourist needs a certain guarantee of good climate. In turn, climate change will lead to an increase in drastic changes in the weather which may even bring us closes to tropical climates, fundamentally in summer. This would lead to increased uncertainty regarding the climatic conditions for the holiday the tourist is trying to plan. This is why the most likely course of action for the tourist would be to take the decision about travelling and purchasing the services at a date much closer to his trip, in order to be able to cancel it without any additional cost, and with more guarantee of sunny, settled weather. Here we would see the reinforcement of a tendency started a few years ago, consisting of waiting till the last week to buy the package tour or the transport ticket and to book accommodation. The development of electronic booking and purchase facilitate this adaptational option

- If we consider the Third Evaluation Report by the IPCC in the year 2001, which states that Mediterranean Southern Europe is the region most endangered by climate change, seen in successive droughts and flooding, and, to the contrary, in Northern Europe there could be benefits for agriculture and regarding the influx of tourists, we can deduce that this greater vulnerability may mean that tourists from Central and Northern Europe may choose to stay at home and to do *domestic tourism* or perhaps travel to other countries in the same geographic area. Thus, there exists the possibility that there will be a lower number of tourists travelling to Spain due to the generalised reluctance of these countries as a result of the uncertainty generated by extreme climate changes or the lack of resources like water.

14.5.2. Adaptational options in the demand

Under these circumstances, there is sufficient reason to believe that the tour operators selling the related goods and services will have to modify determined aspects of their business in the planning of their strategies in the different fields of management. Phenomena of climatic change and its consequences will generate *higher levels of uncertainty* than the ones considered normal in the related business activity. The consequences of this could be:

- In the *first placer*, in the financial calculation of new investments in tourism, the elements of uncertainty due to climate change will have to be incorporated, and these, in turn, will lead to higher levels of risk, and therefore, the *diversion of likely investments towards other sectors* of the economy, in those activities with alternatives, or in the opposite case, a progressive withdrawal of investments.

- In the *second place*, and as a consequence of the previous point, the tour operators will have to establish *strategies to protect themselves to the maximum from these situations of uncertainty.* The high level of seasonality in sun and sand tourism in most areas of Spain, as well as in other types of tourism, like ski resorts, means that determined climate changes affecting the periods of highest demand will give rise to a decrease in financial results. In both cases, the tourist season will suffer alterations with regard to duration and intensity. Thus, the entrepreneur will have to be prepared to deal with financial results less positive than the usual ones in a determined year. As will be seen subsequently, this could lead to the creation of insurance instruments to guarantee the indemnification of these likely results.

- In the *third place*, with regard to short term decisions, the insecurity caused by sudden changes in the weather resulting from climatic change will alter the timing of bookings of travel by the tourist, with an *increase in last-minute bookings* aimed at guaranteeing to a greater extent better and more stable weather conditions. Consequently, the taking of business decisions may suffer big delays in order to better adjust the supply to the demand. The most obvious example, although it is not the only one, has to do with decisions related to prices in the supply-demand adjustment process, as occurs with the typical last-minute offers. For this reason, company management requires higher levels of flexibility, especially in the financial aspect, in order to adjust more rapidly to sudden variations in demand. It is true that the intense development of new technologies will be of great help in this respect, although in aspects like labour or the administration of stocks, changes will be needed.

- Finally, in *fourth place*, companies will have to establish strategies to protect themselves to the maximum from the effects of extreme climate change. For instance, in the construction of buildings, for accommodation or for complementary offer, work will have to be done to protect them from damage or from conditions related to the tourists' wellbeing caused by the aforementioned effects, in order to *guarantee the customers' comfort and safety.*

14.6. REPERCUSSIONS IN OTHER SECTORS OR AREAS

14.6.1. Territorial conflicts over resources

In all countries in which there is a notable variation in climate among the different regions, like in Spain, there are logical substantial differences in the provision of determined natural and energy resources, the use and enjoyment of which is indispensable for tourism as a recreational activity and to satisfy the personal needs of the hundreds of thousands of tourists constituting the real population in a determined region within a specific period of time. This reality gives rise to *two basic questions:*

- In the first place, big problems will arise at the time of allocating these *natural resources* which can be shared by areas and regions. A very clear example is water, because during these climatic processes involving long periods of drought, the existing territorial conflicts will be exacerbated with regard to the supply of zones with a traditional deficit by the zones that have a surplus of the resource in question.

- With regard to *financial resources* mainly from the public sector, some regions could suffer certain consequences of climate change, like a reduction of the sandy beach areas due to a rise in sea level, and this will require engineering infrastructures to protect these areas as much as possible, as well as certain risks in some regions that might be due to catastrophic situations with would require the joint use of large amounts of extraordinary resources. In short, it is very likely that climatic change will necessarily lead to a significant redistribution of public financial resources among the Regional Autonomies in order to deal with these situations, and this could also lead to conflicts between territories.

14.6.2. Transversal repercussions in the economy of the tourist destinations

It seems obvious to think that if climatic change affects the management and results of the tour operators, these consequences will be generalised to *many of the sectors related to tourism* and, in short, the series of economies based on tourism.

In this sense, the *agricultural and industrial sectors* supplying hostelry and restaurant products, above all perishable goods, will have to manage their stock in a more flexible manner in order to adjust to the unforeseeable changes made by their buyers. The consequences of possible change in climate will depend on their duration and intensity.

With regard to *services* it must be pointed out that now more than ever, the companies and tour operators in particular are resorting to the so-called "*outsourcing*" or sub-contracting of work. Logically, these services that are required on specific occasions will be affected to a certain extent by a possible season of lower profits due to a climatological phenomenon. On the other hand, the services that are provided in a continuous manner poor results and which are linked to daily demand will also have to adopt management strategies governed by decisions taken in the very short term.

14.6.3. Repercussion in specific sectors

Considering this sectorial panorama and, specifically, the type of repercussions to be expected from climate change, we must highlight the important role to be played by the financial sector, and in particular, the *insurance sector.* The financial sector will have to make the changes necessary to adjust its activities to the needs of loan funds for unforeseeable events. The insurance sector will undergo multiple changes:

- As the decision to travel will be delayed until just before the leaving, the desire of the tourist to guarantee the trip, weather permitting, will lead to the better development of the *cancellation insurance* for specific circumstances. In this case, not only is the growth of this type of insurance considered, but also an increase of the cover it provides beyond the traditional cover based on problems like health. This new system is very complex, because it depends on indicators and forecasts of climatic instability which are at present non-existent.

- The possibility also exists of insurance typologies that enable the tourist to *claim against determined climatic conditions* once his journey has started. In this case, consideration could be given to the possibility of insurance, from determined insolation levels, based on the normal temperature conditions in the destination visited, to the chance of recovering part of the money spent if certain extreme climatological conditions occur.

- The establishment of *new forms of insurance* will also be used by companies with regard to situations of uncertainty and instability of tourism resulting from climate change. An insurance could be created to cover the possibility of extreme climatological situations, in relation both to its effects and its duration, and this would clearly affect the evolution of the tourism business. It would be an insurance typology parallel to agricultural insurance, which would have to clearly establish the precise climatic conditioning factors obliging the insurance companies to compensate. This insurance might become indispensable in order to provide the guarantees demanded by banks when setting the terms of any type of loan, both for financial investments and for discount operations.

One of the most particularly affected sectors could be the *energy sector* mainly due to increases in energy consumption for the fitting out of tourist establishments (accommodation and restaurants), considering the private demand by the tourists themselves for pleasant temperature conditions in the facilities. The level of energy consumption, as well as other resources like water, is directly proportional to climatic variations in temperature. Even solutions to other problems, like the water supply for coastal areas using desalinisation or purification, or the production of artificial snow in mountain destinations, cause an increase in energy consumption. In Spain, we still have to initiate studied into the development of tourist infrastructures that make use of other sources of energy, alternatives to the traditional ones, or ones that save energy in the use of the existing systems.

Another particularly significant sector is *transport.* According to the IPCC (2001), aviation represents 3.5% of greenhouse gasses, and within a few decades the current growth rate could reach 11%. However, as the objective of this study is to evaluate the effects of climate change on tourism, it must be said that different environmental organisations and institutions recommend that the use of trains or busses for closer destinations be encouraged, and the use of the plane be discouraged, as this type of tourist transport uses a lot of energy. For instance, the daily energy consumption (estimated by the Oficina Federal de Medio Ambiente, the federal environment office, UBA) for a trip from Germany with a stay of 15 days, for the Balearic Isles, is: 317 MJ; Canaries: 732 MJ, Río de Janeiro: 2,101 MJ and México: 2,096 MJ (considering that 100 MJ = 28 KWH).

It is easy to see that any long-distance journey would be seriously affected by any legal restrictions. In the case of Spain, the tourist zones for which the aeroplane is practically indispensable -Canary and Balearic Isles- would be relatively affected in comparison to the rest of Spain, especially if we consider that only a daily consumption of less than 200 MJ is sustainable.

Logically, all the systems of regulations and/or systems of incentives for transport aimed at stopping the pollution process will have big differential impacts on the different transport systems, depending on the technology used.

14.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

In the analysis of the influence and repercussions of the impact of climate change on tourism *there are more uncertainties than certainties,* because there is no information, or at least no reliable data dealing with the possible effects of variations in meteorological conditions. There are many factors affecting global tendencies in tourism, and it is difficult to judge the proportions of this change on only one of these.

The observation of specific, occasional events indicates that tourism is always very vulnerable to natural disasters in the local environment and for a period of time that depends on the scale of the damage and the financial capacity to recover or repair.

From the *perspective of demand*, we are unaware of the possible variations in behaviour resulting from climate change and from the quantitative level of the impact this would cause. In specific terms, we can highlight the *following questions:*

- At what *temperature* does the comparative effect begin to stop northern European tourists from travelling to the coastal areas in southern and eastern Spain, favouring holidays at home?
- What are the possibilities of the tourists, both national and foreign, of *modifying their summer holidays* in order to change them to the autumn and spring seasons?
- Would the *destinations in northern Spain be attractive* if climate conditions were to be modified?
- What are the chances that tourists travelling to Spain will modify their *behaviour,* favouring destinations based more on culture, nature and the rural world, in spite of the predominant image of sun and sand?
- Under what conditions would the tourist lose the *feeling of comfort and* safety in the traditional tourists destinations?

From the *perspective of the agents* acting in the tourism system, the main uncertainties are the following:

- *Political and legal restrictions* for the allocation of resources, such as energy and water supply, in the most vulnerable tourist areas.
- *Capacity for adaptation and transformation* of the present tourism infrastructures and companies with regard to changes in the behaviour of demand.
- *Changes in the interests* of the local agents towards other sectors or economic activities.
- *Changes in uses* or in the degree of utilisation of the natural, cultural and social tourism resources.
- Repercussion in *transport* of restrictions within the international scope (Kyoto Protocol) or the national scope (National Allocations Plan) resulting from agreements on emissions of gasses.
- *Level of compromise* towards other forms of sustainable tourism development and financial capacity to implement them.

As there are no models for quantifying the interrelations between climate and tourism, and the responses to variations in demand, we are unaware of the upper and lower limits of the different climatic indicators that would modify the behaviour of the tourists and the agents in the tourism system.

14.8. DETECTION OF THE CHANGE

14.8.1. Indicators of habitual use according to the tourist zones and products

There are several methods for evaluating climatic potentiality from the tourism point of view. In this respect, a division is normally established between those that make use of *climate-tourism indexes* and those others that analyse *types of weather*:

- With regard to the *climate-tourism indexes***,** it should be pointed out that tourism climatology has often based study of the climate-tourism potentiality of an area on formulae that combine, in a more or less accurate manner, different elements of the climate (Burnet 1963; Cerezuela and Ayala 1987, Davis 1968, Flocas 1975, Hughes 1967, Marchand 1986, Mieczkowski 1985, Poulter 1962, Sarramea 1980). Most of these indices have many points in common, and sometimes they only vary in the number and nature of the parameters considered, or in the relative weight assigned to each of these. The utilisation of these indexes has certain *positive aspects:* in general they are relatively easy to calculate, they accentuate the interdependence of the different elements of climate and they provide one single figure that helps to understand a reality which is often complex and give results that are relatively easy to understand and to interpret. But they also present *less convincing aspects:*

- Most of the indices are calculated with data each one of which is expressed in *its own unit of measurement,* which makes them the object of criticism by many specialists who do not accept sums of magnitudes of a different nature to be mathematically combined.
- The indexes involve *a considerable loss of information* and lead to a high degree of abstraction, fundamentally due to the scale used (monthly measurements and on occasions, three-monthly ones). The climate experienced by tourists cannot be related to the "theoretical" climate defined by the measurements: all the surveys show that the tourist only reacts according to real weather.
- The indexes *rarely incorporate the preferences* shown by the tourists themselves in relation to the conditions they consider optimum for tourism.

• The method based on *weather types* (Barbière 1981, Besancenot, Mounier and de Lavenne 1978, Crowe, Mckay and Baker 1977a, 1977b, 1977c) solves some of these problems by not using measurements and working directly with weather situations experienced on a day-to-day basis by the tourists. Furthermore, it allows for the incorporation of subjective aspects related to perception. The weather types method consists of making a classification of day-to-day situations which are more or less apt for the practice of tourism. These situations or weather types, which are based on several atmospheric parameters, are subjected to an analysis of frequencies within the framework of a determined regional unit.

However, the use of these indicators has never been applied to evaluate the impact of climate change and its effects on the tourism sector. Usually, variations in the *number of tourists* or in the *levels of occupation* of hotels can be used to learn of the possible existence of the consequences for demand of determined climatic conditions at the destination, unusual climatological differentials between the country of origin and the destination (Scott and McBoyle 2001). However, the climatic phenomenon could not be isolated in any case from the other factors that could also have contributed to the results of a specific season, or, to the contrary, that might have counteracted determined climatological factors.

In the future it will be necessary to *develop reliable forecasting systems* integrating climate changes resulting from alterations in ecosystems, with the socioeconomic factors, and in particular, those related to tourism, intervening in a determined area. Interdisciplinary efforts will obviously be indispensable in order to evaluate the extent to which the tourism indicators are or are not influenced by these meteorological phenomena, what degree of retardation can be applied to the effects of climatic conditions or what their long-term consequences will be.

14.8.2. New indicators proposed according to tourism areas and products

The new indicators enabling us to answer the questions posed can be *differentiated according to types of areas and products*, mainly coastal and mountain ones.

Tabla 14.1. *Tourism areas, products and indicators*

COASTAL TOURISM AREAS AND PRODUCTS	
Indicators	**Description**
Energy consumption	Energy consumption (electricity, gas-oil, etc.) is very sensitive to variation in atmospheric conditions. Detailed and diachronic analysis of this indicator at the tourist destinations could indicate climate change.
Water consumption	Increased water consumption at the tourist destinations could be a factor indicating climate change.
Investment in the regeneration of beaches and coastal infrastructures	An increase in extreme events and in sea level would cause damage on the coast which would need to be corrected in order to maintain the efficiency of tourism. The temporal perspective of investments could be considered as an indicators of climate change.
Investment in the installation of interior and exterior spaces	Temperature increases would favour the installation of indoor air conditioning systems, but would also favour the installation of awnings, canopies, fountains and trees outdoors. The temporal evolution of the investments made in this sense could be indicative of climate change.
Duration of stays according to months and seasonal distribution of tourists	Climate changes would cause modifications in the activity schedules: the visits (fewer in the middle summer months and more at the extremes and in the inter-season periods) could also demonstrate climate change.

MOUNTAIN TOURISM AREAS AND PRODUCTS	
Indicator	**Description**
Energy consumption	Energy consumption (electricity, gas-oil, etc.) is very sensitive to variation in atmospheric conditions. Detailed and diachronic analysis of this indicator at the tourist destinations could indicate climate change.
Water consumption	The increase in water consumption for the production of snow in the winter resorts could be an indicator of climate change.
Investment in production of snow	Increased investments in the production of snow and the laying of this could be indicative of climate change.
Duration in days of the winter season	Diachronic analysis of the duration in days of the winter seasons in the different ski resorts could provide information on climate change.
Lower limit of the skiable zones	The annual evolution of the lower limit of skiable zones could demonstrate the phenomenon of climate change.

14.9. IMPLICATIONS FOR POLICIES

The First Conference on Climate Change and Tourism, organised by the World Tourism Organisation in the year 2003, reached the following conclusions related to *public polici*es (WTO 2003):

- Introducing tax incentives or *financial aid* to cover the modification of the tourist infrastructures constructed, in order to deal with the consequences of climate change.
- Considering, wherever necessary, a modification of the tax *system* (for instance, new hotels in more vulnerable coastal areas could pay off their investments in shorter periods of time).
- Incorporating *tax incentives* to encourage the use of traditional building materials.
- Increasing *public investment in infrastructures* for the development of new tourism infrastructures in order to lessen the impact of climate change.
- Adopting, wherever necessary, *legislation* to modify planning policies, demarcation systems and priorities related to the use of the land.
- Introducing *changes in school schedules* to avoid excessive concentration during school holidays.
- Providing *training* to employees in the tourism sector aimed at dealing with the consequences of climate change, including practical assistance in decision-taking.
- Providing training to *recycle workers in the tourism sector* when significant market quotas have been lost.
- Reviewing the *financing policies of the tourism information offices* ensuring that promotion and marketing activities are adapted to the new climatic realities (for instance, promoting inter-seasonality).
- Reorienting *national transport policies*, agreeing, for example, to give less priority to aviation and more priority to national transport.

All these recommendations require the incorporation of *new principles for the public management of tourism,* with the necessary co-ordination among the different areas or sectors involved (economy and taxation, education, labour, environment, infrastructures) as well as among the spheres of responsibility (national, regional and local), with greater participation of the public administration in the management of tourism.

The main and most direct implications would be in regional and local policies. These policies must *revise the existing strategies* for the management of tourism related to occasional and specific increases in demand in certain coastal and rural areas (Parry 2000). Policies should be implemented to reinforce the investments in tourism infrastructures in order to capitalise on new market opportunities in new areas, as well as the necessary *restructuring of determined traditional destinations and products.*

The necessary *public leadership* must go hand in hand with the effort of all the companies in the tourism sector, in order to adapt their activities using cleaner technologies and logistics involving a more rational energy use in order to minimise as far as possible any contribution to climatic change (WTO 2003).

To all of this we must add that it is becoming necessary to orient research towards the *interpretation of possible future scenarios* related to climate, in order to learn of the most likely impacts on tourism (dealt with in the following section). Public incentive is needed to carry out studies aimed at exploring the possible strategic responses of the tourism industry and identifying new expansion opportunities for the markets, joining together public policy makers of tourism, research, private sector and climate experts, who are usually the most productive.

14.10. MAIN RESEARCH NEEDS

This report is of a preliminary nature and its objective is to evaluate the foreseeable impact of climate change on tourism, and also to establish how much knowledge exists regarding the theme and to detect the needs for research, *identifying critical knowledge gaps,* which should be dealt with in the future, and to propose future sectorial or integral research projects, both for whole sectors and for determined geographic areas. This section presents the arguments related to research in the future, in order to objectify the available knowledge and to reduce the uncertainties related to the impact of climate change on tourism in Spain, with the premise of establishing *adaptational strategies* while avoiding alarmism.

As an initial answer, it could be said that *there is little research in Spain into the relationship between climate change and tourism.* The theme is currently in the expectant phase, people are becoming more aware of its importance, but there are still no scientific studies on the possible impacts of climate change on tourism in Spain. Studies by the IPCC and by the UNO, and others associated to these, are being echoed in the media on our country, which is helping to disseminate information about these problems. The institutions and promoters of knowledge of the theme are awaiting confirmation of the scope of climate change (the Third Evaluation Report in 2001 by the IPCC provides data on the verification of this) and of its consequences, in order to take decisions and to implement the corresponding actions. Following an initial phase aimed at defining the problem, the scientific community is beginning to formulate specific objectives and to design methodologies aimed at objectifying the dimension of change and of the specific impacts within each sphere.

Both the research needs and the critical knowledge gaps are projected into the different development phases of the phenomenon and of the research process itself. consequently, the lack of knowledge and the needs for research are identified in the different sections of this Report and in the different items developed in each case, as well as in the *different elements of the Tourism System:* demand, supply, market operators and the geographic-tourism space, particularly in the latter, due to the fact that it encompasses the natural resources with potentiality for tourism and, specifically, atmospheric resources.

In relation to the phases of the study of the phenomenon and its consequences, it should be pointed out that the existence of climate change has been noted throughout the XX century, and that the IPCC has made new predictions about what the climate will be like in the XXI century, basing scenarios of climatic change on trustworthy estimates of the changes observed (likely, very likely,....) and identifying the effects of the change: impacts, adaptation and vulnerability. In order to guarantee the quality level of the IPCC reports, (and to attain greater levels of certainty for trustworthy estimates of the changes observed), *it is necessary to support the research programmes* and to maintain and improve the *networks of systematic observation of the climate* and to implement studies related to the modelling and the physical processes of the climate system.

With regard to the relationship between climate change and tourism, it must be pointed out that there are *research needs* related to:

- The *role played by the present climate in the Spanish tourism system* (see section 14.2 of this Report, dealing with sensitivity to the present climate).
- The *impacts of climate change on tourism*: repercussions for the geographic-tourism space, for supply and demand in tourism, and for the market operators (see section 14.3, on impacts of climate change on the tourism sector).
- Evaluation at different territorial scales and demarcation of *critical and vulnerable zones* (see section 14.4, on the most vulnerable zones).

- The *repercussions for other sectors*, given the transversal nature of tourism; identifying the repercussions for the inputs into tourism (see section 14.6, on repercussions for other sectors or areas).
- The creation of *systems of indicators* in the sector for the detection of change (see sections 14.7 and 14.8, dealing with the main uncertainties and knowledge gaps and the possibilities of detecting change).
- The design of *management models* aimed at optimising the adaptational options and implications for instrumental and regional policies and those related to tourism (see sections 14.5 and 14.9, dealing with the main adaptational options and implications for policies).

In order to structure and to make the aforementioned orientations viable, the following *proposals* were formulated:

1. To incorporate into the present statistics systems and indicators of tourism and the associated activities, *new variables related to the climate/tourism relationship* and the relationship between climate change and tourism. For example, in the System of Environmental Indicators for Tourism (Environment Ministry), in the Statistics System of the General Dept. of Tourism or in other data processing systems related to tourism at national and regional scale.

2. To create a *System of Indicators of the Climate Change-Tourism Relationship*, in order to measure the scope of the impacts of climatic change in the Spanish tourism system. It should integrate indicators, variables or items of all the elements of the tourism system (demand, offer, geo-tourism space, operators), in order to evaluate objectively and in an integral way the impact of climate change and to avail of information for decision-taking. The deficiencies detected indicate the need to identify valid variables and to organise measurement with the corresponding protocol of interpretation and dissemination (designing a data network that considers territorial cover and temporal cover). An analytical approach to the incidence of climatic change on tourism in Spain must contemplate multiple aspects. However, for the sake of operativeness, there should be a simplification of the identification of unique occurrences and reference variables. The system of indicators must include impact indicators, indicators of adaptational capacity and vulnerability indicators, among others.

3. The aforementioned System of Indicators must be based on a series of conditions. The instrumental value of a system of indicators is subject to the fulfilment of a series of prerequisites in the selection and creation of the indicators. The Systems of Indicators must contemplate the *different scales of manifestation of the phenomenon*. The prerequisites are identified according to the different phases of the information gathering process, methodological consistency, scientific validity, application and communication.

4. *Institutionalisation of the promotion and funding of research into climatic change and tourism.* Due to the horizontal and inter-sectorial nature of tourism, and to the structural nature of the dialectics on the climate change-tourism relationship, a specific line for funding for research projects needs to be opened up and maintained, with programmes dealing explicitly with this problem, to be integrated into Plan Nacional de Investigación y Desarrollo e Innovación (PN I+D+I) – (national research, development and innovation plan).

14.11. BIBLIOGRAPHY

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15. IMPACTS ON THE INSURANCE SECTOR

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ABSTRACT

The annual global claims rate of the Spanish non-life insurance market from 1967 to 1981 presents an average of 57%, which rose to an average of 71% for the following decades, up to the present, which is accounted for by the low number of companies operating in the sector compiting aggressively, reducing rates in a context of similar loss level set mainly by the motor and multi-risk branches. Initially, these data provide no obvious evidence of climate change among the determinant factors of this evolution or of their degree of influence therein.

Detecting the effects of climate change on Spain's insurance sector involves the study of the loss rate of key covers, such as floods, storms, frost, hail and drought. In other branches, like health, personal accidents or transport, current figures are not sufficiently clear.

The *Consorcio de Compensación de Seguros* (insurance compensation consortium) is a state Body whose objective is to indemnify damages caused by extraordinary events, including nature-related ones and among these, climatic risks. In the 1971-2002 series, compensation for flooding shows an upward trend, with peaks which involve more significant events every so many years. This evolution is attributed to the higher penetration rate of insurance, to an increase in the exposures insured and to the higher volume of capital insured, which is a clear reflection of the socio-economic development of each moment, but we cannot rule out a certain influence of the effects of climate change, although these are difficult to determine.

The international reinsurance sector highlights the fact that in a possible scenario of increased losses caused by climate change the insurance branches most affected would be property related (residential, industry, engineering and fire), which represent their increased value in areas highly exposed to climatic impact, while health, life and liability could be affected, although initially, to a lesser degree. With regard to distribution according to the type of event, Spain follows the international tendency – storms and floods are the most numerous and costly events.

The agricultural insurance system in Spain, through *Agroseguro*) system has undergone continuous transformation processes to compensate results and to insure the highest number of crops possible through a wide range of cover modalities. For this reason, statistics do not allow the loss rate to be analysed in a homogeneous manner. The geographic distribution of these, however, is the reference of the areas that in the event of a significant deviation from climate parameters, would undergo a modification in agricultural production, and adaptation of farming techniques will therefore continue to be imposed. The East of the Peninsula, due to the high hazard of climate and weather phenomena, and to the concentration of crops sensitive to these variables, has been confirmed as the area most exposed to climate change.

The main research needs of the insurance sector focus upon finding the combination of the hazard, vulnerability and economic value exposed or not, together with insurance modalities, in order to recreate specific historic and probabilistic scenarios for the insurance sector (catastrophe models).

Although no clear evidence of the effects of climate change has been detected in the insurance sector, the variety of possible future scenarios calls for surveillance and for the constant adaptation of the methods and techniques for insurance management of risks related to global warming. The capacity for adaptation and the experience of the CCS (insurance compensation consortium) and of *Agroseguro* constitute a guarantee for the requirements with regard to variations in loss rates. But it will be the manifestation of these variations in practice that will

determine the evolution of these systems in the long term, with regard to the search for appropriate, accessible and socially viable insurance solutions, which also include international reinsurance that is attentive to the requirements of each moment, and to State participation that is sensitive to the pertinent backing required.

15.1. INTRODUCTION

15.1.1. Main parameters

15.1.1.1. Worldwide outlook

In the year 2002 the worldwide volume of premium reached 2,504 billion (USA) EUR, which represents 8.1 % of world GDP (Swiss Re 2003). This amount is broken down into Life Insurance 1,464 billion (USA) EUR and Non-life Insurance: 1,040 billion (USA) EUR.

15.1.1.2. Spanish outlook

In 2002 the *volume of premium* reached 48,972 million EUR in gross earned premium which represents 7% of the GDP (DGSFP – *Dirección General de Seguros y Fondos de Pensiones;* Directorate General of Insurance and Pension Funds – 2003). In Great Britain this percentage is 15%; in Switzerland 13%; in South Korea 12%, and in Japan 11%, (Swiss Re 2003). The 2002 volume of premium is broken down into Life Insurance 26,810 million EUR and Non-life Insurance 22,162 million EUR.

Table 15.1 compares the evolution of the main parameters of the sector from 2000-2002.

Table 15.1. *Main Parameters of the Insurance Sector in Spain (2000 – 2002). Source: DGSFP (2003)*

Million EUR	2000	2001	2002
Life and Non-life Gross Earned Premium	41,858	42,763	48,972
Gross Premium / GDP at market prices (%)[1]	6.8	6.5	7.0
Gross Premium / Inhabitant	1,033	1,040	1,170
Non-Life Gross Premium	17,421	19,319	22,044
Loss experience (losses/premium) Gross (%)	75.7	73.9	69.8

The Spanish share *of the world market* is 1.7 %, whereas that of the USA is 38%; for Japan it is 17%; for Great Britain 9%; and for Germany 5%. With regard to expenditure per capita in Spain, this reaches 1,170 EUR; in Switzerland, 4,693 EUR; in Great Britain 3,698 EUR; In Japan 3,335 EUR; and in USA 3,300 EUR (Swiss Re 2003).

In order to give an idea of the *importance of each line of business* in the Spanish non-life insurance market, it is now included according to them and comparison is made between 2001-2002 (table 15.2).

[1] **GDP at m.p.=** GDP at market prices.

Table 15.1.2. *Volume of premium per line of business. Non-life Business. Source: DGSFP (2003)*

LINES OF BUSINESS/PREMIUM (Million EUR)	2001 Premium	2002 Premium	2002 Distribution (%)
Motor	8.840	9.870	44.7
Multirisk	2.771	3.339	15.1
Health Care and Sickness	2.994	3.269	14.8
GTPL	842	1.107	5.0
Burial Insurance	996	1.069	4.8
Other Damage	570	841	3.8
Accidents	691	730	3.3
Credit Insurance and Bonds	459	512	2.3
Transport	395	497	2.2
Assistance	428	378	1.7
Fire	152	224	1.0
Legal Defence	123	126	0.5
Business Interruption	58	82	0.3
TOTAL	19.319	22.044	100

As can be seen in table 15.3, from 1970 to 2002 the *number of insurance companies* has dropped sharply, and if this decrease is already significant in the case of Limited Companies, it is more so if we talk of the Mutuals or the reinsurance companies, although these latter ones were already very few.

To the number of companies inscribed on the Register of the DGSFP on December 31st 2002, that is to say, a total of 399 (compared to 684 in 1970), we must add 351 European companies authorised to operate in Spain through the Freedom to Provide Services System.

Table 15.3. *Private insurance companies classified according to their legal status. Source: DGSFP (2003)*

Direct Insurance Companies	1970	1980	1990	2000	2001	2002
Corporations	479	494	391	259	251	247
Mutuals	139	136	75	52	51	47
Branches of Foreign Companies	55	39	31	39	37	37
Social Benefit Mutuals	--	--	--	69	70	65
Total Direct Insurance Companies	**673**	**669**	**497**	**419**	**490**	**396**
Specialised Reinsurance Companies	11	13	8	4	3	3
Total Insurance Companies	**684**	**682**	**505**	**423**	**412**	**399**

The *number of insurance brokers* (individuals and companies) authorised in Spain at the end of the year 2002 was 4,820. Of these 1,576 are authorised by the Regional Autonomies and the rest, 3,244, by the DGSFP.

15.2. SENSITIVITY TO THE PRESENT CLIMATE

15.2.1. Milestones in the history of the Spanish Insurance business

1412.- Chapters of the Tortosa Court. First document defining and regulating insurance (slaves runaway).

1428.- First specific insurance protocol (Bartolomé Massous, Barcelona notary).

1428.- The oldest known Marine contract signed in Spain.

1435.- The Barcelona City Council creates the first fixed premium insurance institution (marine: cargo and hull).

1537.- The Burgos Traders' University creates the first standard model of an insurance policy (marine activity).

1539.- Rules by the Seville Consulate.

1553.- Rules by the Burgos Consulate.

1737.- Rules from Bilbao. Trade regulations applied in Spain until the Trade Law was approved.

1785.- The first Spanish company working in the fire line of business is created, which is also the first company with shareholders and the first one in Spain to cover risks different from the marine ones: Real Compañía de Seguros Terrestres y Marítimos de Madrid (Madrid Royal Marine and Terrestrial Insurance Company) .

1822.- The first mutual residential fire insurance company is set up in Madrid.

1829.- The first Commercial Code is approved, regulating marine and terrestrial transport.

1842.- The first Fixed Premium Insurance Company is set up covering hail: "El Iris".

1846.- The mutual insurance company of crop and livestock is set up, loans for cereals and capital startup.

1859.- The "Protección Agrícola" (Agricultural Protection) for the crop insurance is set up.

1885.- New Commercial Code, regulating fire, life and terrestrial transport insurance.

1897.- "La Unión Agrícola y Pecuaria" (Agricultural and Livestock Farming Union), is set up in Madrid insuring fire, life, crops and livestock.

1900.- Law covering labour Accidents (work accident insurance).

1902.- First Bill for Agricultural Insurance.

1908.- Instituto Nacional de Previsión (National Benefits Institute).

1908.- First law regulating the private insurance activity in Spain. The regulations governing it date from 1912. Both provisions stipulate the creation of supervising and control organisms (Comisaría General de Seguros, Inspección de Seguros, -General Commission for Insurance, Insurance Inspection -etc).

1910.- Popular Insurance Mutual (Health).

1915.- First Association of Insurance Brokers (Barcelona).

1919.- Compulsory Workers' Retirement Insurance.

1919.- The National Mutual of Agricultural and Livestock Farming Insurance (Mutualidad Nacional de Seguros Agropecuarios) is set up, and serves as a base for the Agricultural Insurance System (Sistema de Seguros Agrarios) under the auspices of the State.

1928.- The Compulsory Travellers Insurance is created.

1928.- Creation of the Export Credit Insurance.

1928-1929.- The Compañía Española de Seguros de Crédito y Caución, S.A. (Spanish Credit Insurance and Bonds Insurance Company) is set up.

1931.- Maternity Insurance.

1940.- The National Rural Insurance Service (Servicio Nacional de Seguros del Campo) is set up.

1940.- Arbitration Court for Insurance.

1941.- Law on Social Benefit Mutuals (Mutualidades de Previsión Social).

1941.- The Riot Risks Compensation Consortium (Consorcio de Compensación de Riesgos de Motín) is set up.

1941.- The collective insurance policy is signed (between the Telefónica and the "Sudamérica").

1942.- The Compulsory Heath Insurance is instituted.

1944.- The Riot Risks Compensation Consortium becomes the Risks on Property Compensation Consortium (Consorcio de Compensación de Riesgos sobre las cosas).

1954.- Law regulating Private Insurance in place of the one from 1908.

1954.- To replace the Compensation Consortia in force at the time, an only Insurance Compensation Consoritum (Consorcio de Compensación de Seguros) is set up.

1962-1965.- Compulsory Motor Insurance is instituted.

1963.- The Social Security System was created.
1964-1967.- Nuclear risk insurance was regulated.
1970.- The Compañía Española de Seguros de Crédito a la Exportación, S.A. (Spanish Export Credit Insurance Company) was set up.
1978.- The Multiperil Crop Insurance Law was approved.
1980.- Agroseguro (agricultural insurance pool) was set up.
1986.- New Regulation on Extraordinary Risks. The surcharges are applied on the insured capital instead of being a percentage of the original premium.
1991.- Legal statute of the Consortium. Public Business Institution. End of the monopoly on the extraordinary risks coverage.
2004.- New regulations on Extraordinary Risks. The business interruption is included in the extraordinary risks coverage.

(Del Caño 1983; *Maestro* 2000; *y Burgaz y Pérez-Morales* 1996)

15.2.2. Natural hazards insurance in Spain related to climate change

The specific insurance covers are detailed for *rain, floods, wind* and *temperature variations*, as well as some of their manifestations (i.e. hail, tornadoes), as these are the natural phenomena most likely to vary in behaviour (intensity and/or frequency) due to climate change.

With regard to types of risks, the generic one of property is here considered, the specific *agricultural* risks, due to their sensitivity to the climate and the risks involved in engineering.

Likewise, a section is dedicated to the *Consorcio de Compensación de Seguros (CCS),* due to the important role it plays in the extraordinary risks coverage in Spain[2]. The CCS is a Public Business Institution, with its own legal personality and the full capacity to operate, holding its own assets, different from the State, and subjected in its activities to laws ruling private companies. The aim of the CCS is to compensate for the losses caused by extraordinary events, including natural disasters and among these, climate risks. Its activity has a subsidiary nature, as it will only indemnify when the private insurance company does not cover the extraordinary risk or, covering this, it is insolvent.

15.2.2.1. Property Risks

Precipitations: The private insurance market covers material damage caused by the precipitations (rain, hail or snow) which can either be considered as “atypical and extraordinary” or whose intensity is greater than one single value for the whole Iberian Peninsula.

Claims must be backed with a certificate from the Instituto Nacional de Meteorología (INM) – Met Office – with data from the closest observatory (or observatories) to the loss location.
Private insurance covers losses caused by water leaking through roofs, balconies or windows, as a consequence of filtration in roofs or the overflowing of gutters and hanging drainpipes. Losses caused by hail and snowing of any intensity (including weight of the snow) are also covered. Losses are excluded in case of leakage on ground floors, underground or sewage, or if they are the consequence of poor building maintenance.

[2] According to the regulations on the Extraordinary Risks Insurance approved by Royal Decree 300/2004 dated February 24th.

Floods: The private insurance market does not cover the damage caused by floods. See section 15.2.2.4 on the Consorcio de Compensación de Seguros (CCS).

Wind: The private insurance market usually defines its liabilities regarding losses due to wind when this surpasses one single speed value (km/hour) for the whole country. An INM certificate must support claims with data from the closest observatory (or observatories) to the loss location. For damage caused by strong winds (3 seconds gusts over 135 km/h) and tornadoes, CCS will be liable.

15.2.2.2. Agricultural Risks

Precipitations: Voluntary hail, torrential rains and/or continuous rain insurance for farmers with different rates according to zones and crops. It is developed in the context of the Spanish System of Multiperil Crop Insurance, with private participation through insurance companies integrated into a pool managed by Agroseguro and state participation through the CCS.

Floods: Voluntary floods insurance for farmers with different rates according to zones and crops.

Wind: Voluntary insurance covering wind and/or Sirocco for the farmer with different rates according to zones and crops.

Variations in Temperature and Humidity: Insurance of Frost, Drought and Heat-waves (Scorching) voluntarily by the farmer with different rates according to zones and crops.

15.2.2.3. Engineering Risks

Precipitations and Wind: There is a widely used clause on the market, which indicates that the insurance company will cover the losses caused by “climate phenomena” the magnitude of which surpasses that corresponding to a 10 years return period. The compensation is conditioned to the design and execution of the property insured being subject to the regulations in force and to the required safety measures.

Floods: The private market covers floods through a clause similar to the ones on “Climate Phenomena”, which indemnify losses resulting from a precipitation value equal to or higher than that corresponding to a return period (10 20 years).

15.2.2.4. Consorcio de Compensación de Seguros (CCS)

The indemnities of the CCS are conditioned by the existence of an insurance policy in force in certain lines of business, in which the private market does not assume the losses derived from certain extraordinary risks.

Precipitations: The CCS will not be responsible for damage caused by the direct rain, if this is the only agent of the loss. Please consult definition of Atypical Cyclonic Storm (Tempestad Ciclónica Atípica).

Floods: Covers “extraordinary floods”, which is defined as the “floods of the terrain caused by the direct action of the rainwater, from the thaw or from lakes with a natural exit, from the rivers or tributaries of the natural courses of surface water, when these overflow from their natural courses, as well as sea damage. This will not be seen as such if caused by water from dams, sewers, drains and other subterranean courses, built by man, on bursting, breakage or breakdown due to facts that do not correspond to risks of an extraordinary nature covered by the CCS, or by rain that has fallen directly onto the insured risk, or that collected by its roof or terrace roof, its drainage network or its patios”.

Wind: The CCS covers the losses caused by winds defined as an Atypical Cyclonic Storm, among which are included “Extraordinary Winds” and “Tornadoes”.

The data on the atmospheric and seismic phenomena, volcanic eruptions and fallen heavenly bodies were obtained through certified reports issued by the INM, the Instituto Geográfico Nacional (IGN - National Geographical Institute) and other expert public agencies.

Business interruption: With regard to the cover of extraordinary risks by the CCS, it is considered that a business interruption takes place when, as a consequence of certain extraordinary events included in the cover, there is an alteration of the normal results of the economic activity of the insured subject, deriving from the paralysis, suspension or reduction of the production processes or business of the aforementioned activity.

Exclusions by the CCS in relation to Extraordinary Risks

In respect of the *direct cause* of the loss, the CCS will not be responsible for damages derived from:

- Direct rainfall on the insured risk or that collected by its roof or terraced roof, its drainage network or its patios.
- Hail, weight of the snow and non-extraordinary winds (gusts of three seconds below 135 km/h).
- Leaks, filtration or dampness.
- Breakage of dams, sewers or artificial canals (unless the breakage was caused by an extraordinary event).
- Elevation of the phreatic level, movement of slopes, landslides or settling of land, rockfalls or similar phenomena, unless these were caused by rainfall which in turn had caused extraordinary floods in the area and that they happened simultaneously to the aforementioned flood.
- Swell or ordinary flows when they affect properties, which are totally or partially permanently submerged.
- Events, which due to their magnitude or seriousness are classified by the Spanish government as a “national catastrophe or calamity” (this classification has never been applied in the history of the CCS, in spite of the big losses caused by certain catastrophic events).

15.2.3. Statistics 1967-2002 from the (DGSFP) – (Directorate General of Insurance and Pension Funds). Written premium and loss rate of non-life lines of business, direct insurance

The evolution of the Spanish non-life insurance market, with regard to premium and losses, has been gradually approaching the parameters of foreseeable behaviour in a developed country within the environment of the European Union. It began with a very low level, which in 1967 in acquired premium represented 161 million EUR, which was multiplied by 10 in 1979, and by 100 in 1995. Here it can be seen that the percentages of the loss rate/premium relationship gradually increased. Thus, from 1967 to 1981 this relationship stayed at between 50 and 60 per 100, with an average of 57%, whereas from 1982 to 2002 the average was at 71%, with a minimum of 63% in 1982, and a maximum of 78% in 1991 (figure 15.1).

The reasons for this evolution lay, from a general point of view, in the greater control and regulation of the market with regard to reorganisation, which led to a significant reduction in the number of companies in a context of increased competition in the sector, due to the improvement of management and marketing policies. But above all, one must take into account the behaviour of certain lines of business, the weight of which was reflected in the whole Non-Life area, as is the case of Motor (MTPL) and other covers) the loss rate of which in 1989 represented 58 % of total Non-Life claims, its premium totalling, in the same year, 47% of the global amount of premium in this market. The same can be applied to the Multirisk line of business.

In Motor, it must be pointed out firstly that the Spanish car pool underwent a steep increase following the seventies, which, in the absence of prevention measures and with a deficient roads network, led to an increase in claims. And secondly, the rise in the compensation limits in order to respect the minimums imposed by community regulations for the obligatory insurance was to be clearly felt in the payment of claims.

With regard to Multirisk, the marketing of these insurances half way through the seventies not only meant the binding together of the old burglary and fire insurance, among others, in one policy, but also the extension of covers, in parallel with a better knowledge of the insured parties about their compensation rights. The result was to be a turn also in claims, fundamentally in residential insurance and SME's.

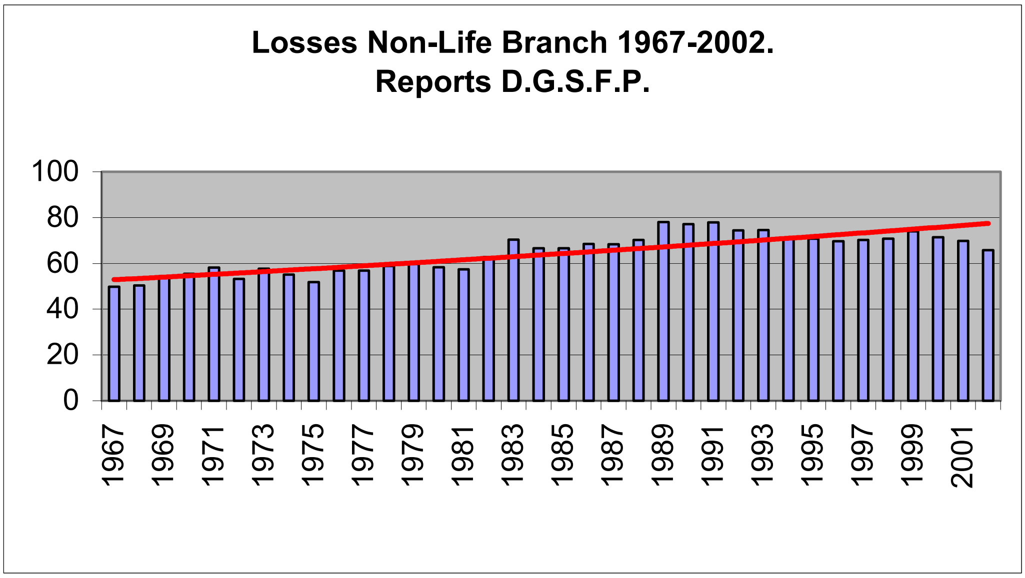


Fig. 15.1. *Statistics Losses 1967-2002 Non-Life Sector in Spain. Source: DGSFP Reports*

15.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

15.3.1. Extraordinary Risks Coverage

Data from the main reinsurance companies and other worldwide insurance institutions indicate that in recent times, the worldwide loss rate related to climate events (including extreme events) has increased in frequency and intensity.

Along the same lines, the Third Report on Climate Change (2001), using data from the sector, assumes and incorporates this evidence on the increase in claims, and predicts that it is in the field of insurance where the effects will be most felt. It is a question of finding out if this panorama will be reflected in Spain and whether it is possible (and to what degree) to attribute this increase in claims, if it were to be proven, to the phenomenon of climate change.

When reviewing the behaviour of claims related to natural catastrophes in Spain, we must make an important exception: that the statistical data available on losses compensated by the CCS cover at most the last 30 years, so that, dealing with this type of loss rate, the series is excessively short with regard to establishing serious conclusions.

15.3.1.1. Large events

In the nomenclature of the CCS, the “extreme events” are called "large events", and are considered to be so if they have led to payments of over 12,000,000 EUR, since 1992 (CCS 2003).

In the series from 1977 to 2002, 32 large events were accounted (table 15.4.) All of these, except the one that occurred in April 1982 (ETA terrorist attack against the Telefónica building, Ríos Rosas street in Madrid), are natural events. And of these 31 remaining events 29 correspond to phenomena related to floods and 2 events to floods and atypical cyclonic storms together (in Extremadura in November 1997 and in the Balearic Islands in November 2001).

In table 15.4, 7 out of the 10 losses of highest compensation paid by the CCS correspond to the 80’s decade including the 4 most costly losses. The 3 left happened during the 1990-2002 period.

15.3.1.2. Large flood events

In order to obtain the most homogenous data possible, we only took the large flood events (table 15.5). It must also be taken into account that in the CCS statistics for years previous to 1987, the “large events” related to floods include losses caused by rain, wind and snow. Since then, they have been specifically considered under the epigraph “atypical cyclonic storm”.

As it is not possible in the large events previous to 1987 to establish the losses due to rain and those resulting from floods, and in order to be able to compare them with those that, after this time, correspond exclusively to floods, we calculated the percentage that in the general losses of each year previous to 1987 corresponds to rain, wind and snow (atypical cyclonic storm), deducing this percentage, according to each year, from the different large floods events. Logically, on doing this operation, some of the events have been excluded from the table as they did not reach a sufficiently high figure to be considered as “large events”.

It can be seen that some of the previously indicated characteristics of the 10 most important events continue to exist with regard to indemnities paid by the CCS, 6 are maintained in the decade of the 80’s, including the 4 highest losses, and the other 4 in the 90’s. The amount of the indemnities paid by the CCS from 1980 to 1990, for 11 large floods events reached a figure of 1,109,551,537 EUR, whereas the payments for the period 1990-2000, for 13 large events, reached 500,479,267 EUR, half the amount of the previous decade.

Table 15.4. *Large events. Property damages. Extraordynary Risks (EUROS)*

	MONTH AND YEAR OF OCCURRENCE		LOSS LOCATION	CLAIMS	COMPENSATION AMOUNTS (nominal)	COMPENSATION AMOUNTS (updated)
1º	JUNE	1977	Basque Country	3.889	7.842.757	49.822.373
2º	JANUARY	1980	C. of Valencia	390	7.436.635	30.835.697
3º	APRIL	1982	C. of Madrid	46	14.975.833	45.639.676
4º	OCTOBER	1982	C. of Valencia	9.136	60.217.813	171.879.513
5º	NOVEMBER	1982	Catalonia	1.587	15.899.787	44.889.872
6º	AUGUST	1983	Basque Country	24.802	248.266.592	642.103.010
			Cantabria	761	2.192.059	5.669.420
			Navarre	101	254.985	659.479
			TOTAL:	*25.664*	*250.713.636*	*648.431.909*
7º	NOVEMBER	1983	Catalonia	3.899	8.221.845	20.661.293
			C. of Valencia	2.947	8.086.492	20.321.154
			TOTAL:	*6.846*	*16.308.337*	*40.982.447*
8º	OCTOBER	1984	Galicia	4.207	14.424.110	33.413.534
9º	JULY	1986	C. of Valencia	4.327	10.817.899	21.792.716
10º	OCTOBER	1987	Catalonia	3.243	13.214.694	24.803.938
11º	NOVEMBER	1987	C. of Valencia	17.277	115.147.717	215.323.391
			R. of Murcia	1.523	3.064.633	5.730.788
			TOTAL:	*18.800*	*118.212.350*	*221.054.179*
12º	JULY	1988	Basque Country	2.322	22.741.620	40.996.457
13º	SEPTEMBER	1989	C. of Valencia	4.163	18.144.555	30.390.344
			R. of Murcia	984	4.633.371	7.760.440
			Balearic Islands	421	3.714.327	6.221.132
			East Andalucia	431	3.458.602	5.792.818
			TOTAL:	*5.999*	*29.950.855*	*50.164.734*
14º	NOVEMBER	1989	East Andalucia	7.266	70.219.964	116.310.862
			West Andalucia	170	3.254.895	5.391.339
			C. of Valencia	112	1.342.661	2.223.955
			TOTAL:	*7.548*	*74.817.521*	*123.926.159*
15º	DECEMBER	1989	C. of Madrid	97	15.721.178	25.895.837
16º	OCTOBER	1991	C. of Valencia	5.116	16.099.522	23.813.936
17º	JUNE	1992	Basque Country	3.103	20.882.292	29.833.676
18º	OCTOBER	1994	Catalonia	4.631	46.830.863	59.902.115
19º	SEPTEMBER	1995	Catalonia	3.664	20.203.720	24.909.943
20º	SEPTEMBER	1996	C. of Valencia	3.114	12.642.405	15.063.998
			Catalonia	1.594	5.673.158	6.759.825
			Balearic Islands	313	1.320.540	1.573.483
			TOTAL:	*5.021*	*19.636.103*	*23.397.306*
21º	DECEMBER	1996	West Andalucia	1.154	22.867.597	27.034.053
22º	JUNE	1997	Basque Country	5.701	72.555.488	84.929.938
23º	SEPTEMBER	1997	C. of Valencia	7.494	38.202.020	44.496.599
24º	NOVEMBER	1997	Extremadura	3.006	18.951.322	22.001.214
25º	FEBRUARY	1998	East Andalucia	985	23.591.151	27.279.302
26º	SEPTEMBER	1999	Catalonia	6.539	34.515.763	38.615.214
27º	JUNE	2000	Catalonia	2.952	27.510.603	29.965.433
28º	OCTOBER	2000	C. of Valencia	6.914	65.763.977	70.701.844
			R. of Murcia	2.042	8.344.700	8.971.259
			TOTAL:	*8.956*	*74.108.677*	*79.673.103*
29º	SEPTEMBER	2001	C. of Valencia	3.430	30.047.419	31.458.146
30º	NOVEMBER	2001	Balearic Islands	6.901	24.607.222	25.648.391
31º	MARCH	2002	Canaries	1.920	34.694.884	35.730.611
32º	AUGUST	2002	Basque Country	4.609	20.204.327	20.470.204
TOTAL				**169.283**	**1.218.803.997**	**2.203.688.226**

Data at September 30th 2003; Updated at 31st December 2002. Source: CCS, 2003.

.

Table 15.5. *Large flooding events*

Month and year of occurrence	Loss location	*EUROS* **Compensation Amounts (nominal)**	*EUROS* **Compensation Amounts at 31-12-2001**
June 1977	Basque Country	5.568.357	34.443.899
January 1980	C. of Valencia	1.323.721	5.344.454
October 1982	C. of Valencia	34.805.896	86.734.526
November 1982	Catalonia	9.190.077	25.264.213
August 1983	Basque Country, Cantabria, Navarre	189.790.222	477.958.086
November 1983	Catalonia, C. of Valencia	12.345.411	30.208.094
October 1987	Catalonia	13.214.694	24.151.838
November 1987	C. of Valencia, R. of Murcia	118.212.350	215.242.628
July 1988	Basque Country	22.741.620	39.918.654
September 1989	C. of Valencia, R. of Murcia, Balearic Islands and East Andalucia	29.950.855	48.845.895
November 1989	East and West Andalucia, C. of Valencia	74.817.521	120.668.119
December 1989	C. of Madrid	15.721.178	25.215.031
		522.113.545	**1.109.551.537**
SUBTOTAL	Basque Country (August-83) and C. of Valencia (November-87) excluded	**214.110.973**	**416.350.824**
October 1991	C. of Valencia	16.099.522	23.187.864
June 1992	Basque Country	20.882.292	29.049.344
October 1994	Catalonia	46.830.863	58.433.746
September 1995	Catalonia	20.203.720	24.255.057
September 1996	C. of Valencia, Catalonia, Balearic Islands	19.638.386	22.784.835
December 1996	West Andalucia	22.870.109	26.326.214
June 1997	Basque Country	72.624.932	82.776.266
September 1997	C. of Valencia	38.237.438	43.366.946
November 1997	Extremadura	16.869.297	19.069.253
February 1998	East Andalucia	23.487.433	26.445.345
September 1999	Catalonia	34.731.364	37.834.880
June 2000	Catalonia	27.751.601	29.433.239
October 2000	C. of Valencia, R. of Murcia	74.049.252	77.516.277
		434.276.209	**500.479.267**
September 2001	C. of Valencia	29.554.450	29.751.954
TOTAL		**991.512.561**	**1.674.226.657**
Based on data from CCS			

If we exclude from table 15.5 the 2 losses with the greatest return period (marked with an asterisk), and which in this series could be considered "atypical", such as the floods in the Basque Country in 1983 and those in Valencia in 1987, the result is a more equal distribution of the 10 most costly losses in this series: 5 in each decade, although the two most important ones are still in the 80's. Furthermore, it can be seen that the amounts totalling the two decades invert, as was to be expected, their tendency. Thus, from 1980 to 1990 there are payments for 416,350,824 EUR (corresponding to 9 events), whereas from 1990 to 2000 indemnities reach 500,479,267 EUR (corresponding to 1,313 events). It must be kept in mind that we are dealing with updated amounts.

15.3.1.3. All the events due to floods

If we exclude from the valuation of the losses due to floods the two big ("atypical") losses mentioned for 1983 and 1987 the potential line of tendency is presented in figure 15.2. Thus, we obtain an ascending trajectory of the line, punctuated every few years by significantly larger events, in periods that are distributed in quite a homogenous manner.

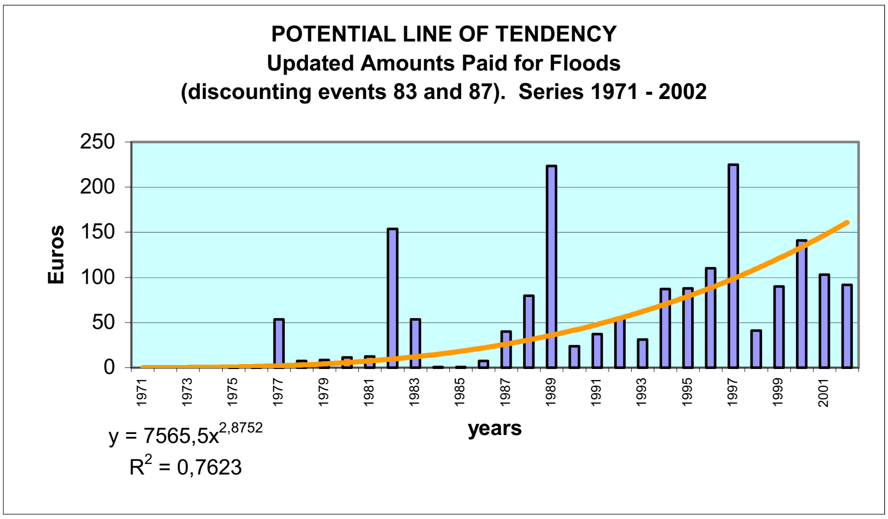


Fig. 15.2. *Based on data from the CCS*

15.3.1.4. Conclusion

To blame climate change for this loss cost evolution obtained through different ways is not sufficiently founded. It is difficult, without any other evidence, to attribute this evolution to factors different to the insurance penetration, the increase of exposed insured properties and the greater volume of insured capital.

From a worldwide perspective, it will also be complicated to calculate in real terms the incidence of climate change in the rise of the loss rate. In a recent Munich Re publication an expert author asked the question: “why floods are becoming more frequent and more costly?”, and he asked in the following manner: “The increase in flood losses in recent years and decades is primarily attributable to the booming development of areas near rivers and lakes”, along with “carelessness, ignorance, and profit-seeking” (Kron 2003). Then, it seems that climate change is not among the most determinant factors in the increase of these losses.

With regard to these considerations, Pamela Heck, a climatologist from the **Swiss Re** Department of Catastrophic Hazards, stated the following in an interview: “Insured losses increased exponentially during the past 30 years. This increase is mainly due to economic, demographic and geographical factors, such as the rapid increase in property values, their concentration in highly exposed areas and the high vulnerability of modern technology. The actual impact due to climate change is, however, difficult to quantify”. This climate expert subsequently insists that the future impact of climatic change and of extreme climatic events in the tendency towards losses is difficult to quantify, however, “certain measures will have a direct impact on loss reduction”, referring to the prevention and mitigation of risks (Swiss Re 2004a).

15.3.2. International Reinsurance

A suitable valuation of insured losses resulting from natural elements takes into consideration all the circumstances, that is to say, the increase in the concentration of people and economic properties, increased vulnerability, the new technologies and, most important, greater insurance penetration in the Spanish market. This series of reasons may make one think that the increase in losses is not exclusively due to climate change, and one must keep in mind that all the already mentioned factors will continue to play their role, and their effects will certainly augment. From this point of view and thinking of the insurance sector, “what is being discussed is not the scale of the actual weather event, but the financial consequences of the claims made upon the insurance industry” (Sammonds 2002).

As a clear example of this concern, we highlight the comments made by the Reinsurance Association of America, which pointed out that 50% of the total insured losses throughout the world over the last 40 years resulting from natural events, including those of geologic origin, have occurred since 1990. If this rhythm continues, the intervention of the governments in the different countries may become necessary to deal with such losses.

In the possible scenario of increased losses, the insurance lines of business that will be most affected must be indicated. The first of these is the one known as “property”, which includes property, industry, engineering and fire, and is representative of the increase in the value of the properties in areas highly exposed to climate impact. Other lines of business such as health care, life and GTPL, may be affected, although initially, to a lesser degree.

Fig. 15.3 shows a result very similar to that obtained by the CCS for a comparable period of time. In spite of the fact that the number of claims is low, the accumulation of these over the last decade is significant (1994 – 2003) as is the increase in the economic cost of the losses generated, due to the fact that the figures have been indexed.

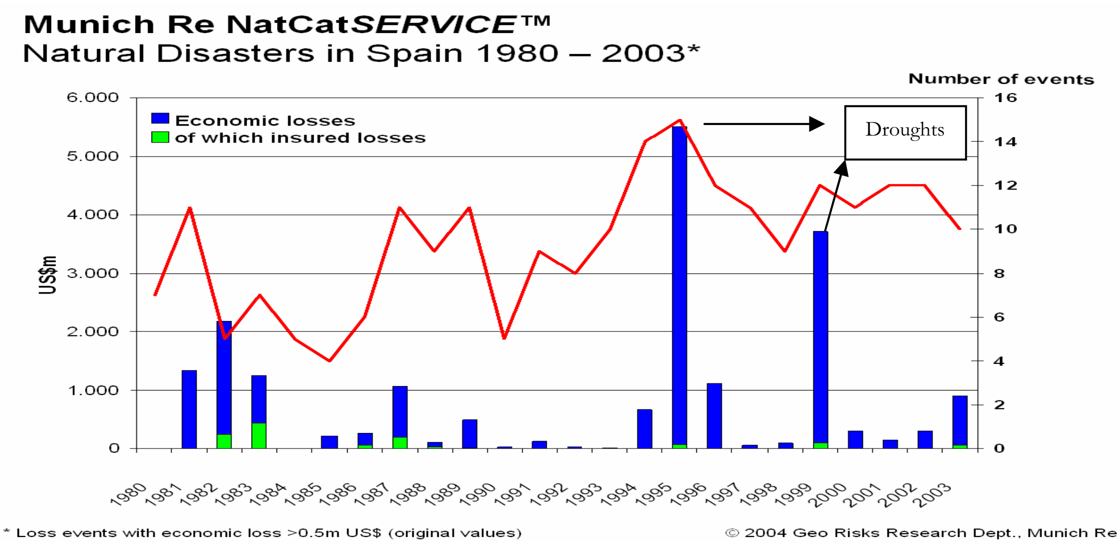


Fig. 15.3. *Natural Disasters in Spain (1980 – 2003)*

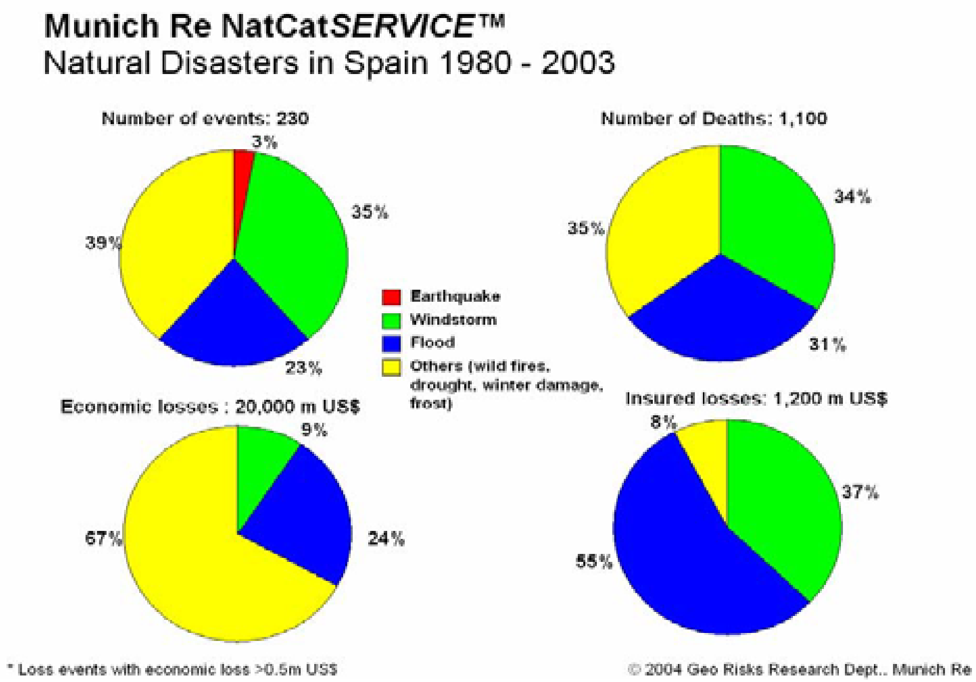


Fig. 15.4. *Distribution of natural disasters in Spain 2 (1980 – 2003). Source: Geo Risks Research Department, Munich Re*

It is also important to identify the zones in which these losses have occurred, as the density of the insurance and the economic value of the property is not the same in urban and rural zones. For example, the hailstorm of August 2003 in parts of Southern Aragón; should this event had happened in urban areas such as Madrid or Barcelona, it would have meant much higher losses.
In reference to the distribution per type of event, Spain follows the international tendency, as storms and floods predominate (fig. 15.4). Munich Re confirms this fact in their 2003 catastrophes study (Munich Re 2003), which indicates that 76 % of insured losses are due to storms and 8 % to floods. In Spain, and with regard to insured losses, floods are more frequent than storms. Due to the fact that Munich Re's procedures for the evaluation of insured and economic losses are not the same as those of the CCS, the data are not comparable.

15.3.3. Agricultural sector

Within the insurance sector, agricultural insurance, for obvious reasons, is the most sensitive to climatology and meteorology. Furthermore, in Spain there has been a long tradition related to the search for optimum formulae for insuring crops against climate hazards, until the current one in force was established, which is an exemplary model of agricultural policy from the insurance sector.

Although the history of agricultural insurance in Spain can be documented since 1902, (Burgaz and Pérez-Morales 1996) with statistical backup, it is not until the year 1940, after the Spanish Civil War, that the State implemented the "System of Agricultural Insurance". Since that year and up to 1980, statistics are available for losses of crops due to hail, but there are no reliable data for floods, droughts, storms, frost or other hazards. There is, however, information on State Aid for Calamities (Ayudas del Estado a las Calamidades), which can be identified with events different from hail, but which is not specified. Since 1980, and introduced by Multiperil Crop Insurance Law 87/1978, cover of frost, wind, rain, floods, etc., has gradually and selectively been added.

Fig. 15.5 shows the loss rate for the 1967-2002 period (the period observed equalling the one in table 2.1) of the total agricultural insurance, where a turn can be observed (350%) in the year 1972, when a crisis occurred in the insurance system due to the high loss rate, which led to the drafting of new technical regulations (rate for hail 1973). Other years with significant losses are 1983 (209%), with floods in the Basque Country; 1986 (242%) with spring frosts and 1992 (265%) with a severe drought. The tendency drops gently for the period studied, showing the compensatory effect of the adjusted rates per crop and zone in the Spanish agricultural insurance system.

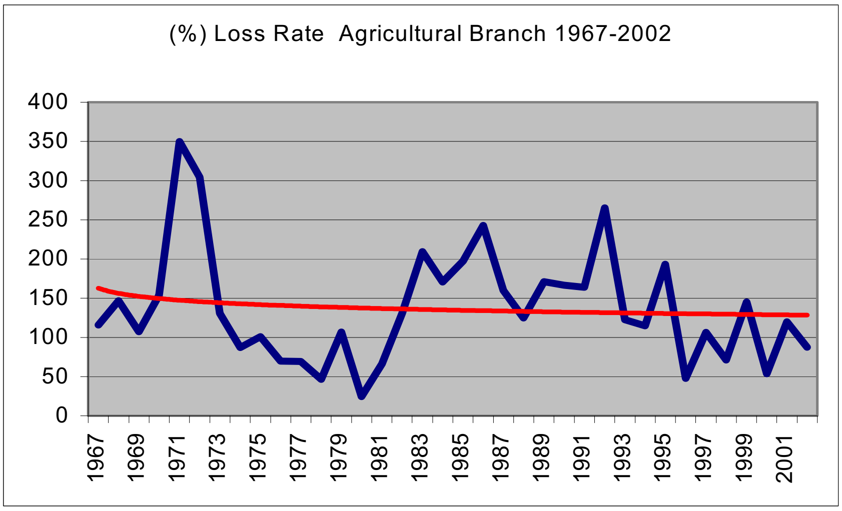


Fig. 15.5. *Source: Based on data from Burgaz and Pérez-Morales* 1996, *and information from Agroseguro (2003). Loss rate in blue; logarithmic tendency line in red.*

Fig. 15.6 enables us to differentiate between the percentage distribution of the number of claims in agricultural insurance to Agroseguro, due to certain causes. The 5 most significant categories have been selected (for this reason none of the columns reach 100%, although annual data are considered that contemplate 80% or more of the claims), leaving fire, several types of wind and sickness out of the graph due to their lower level of incidence. Noteworthy in the first place is the number of claims following to hail, as this cover involves 50% of the agricultural insurance premium for the series 1987-2002.1987-2002.

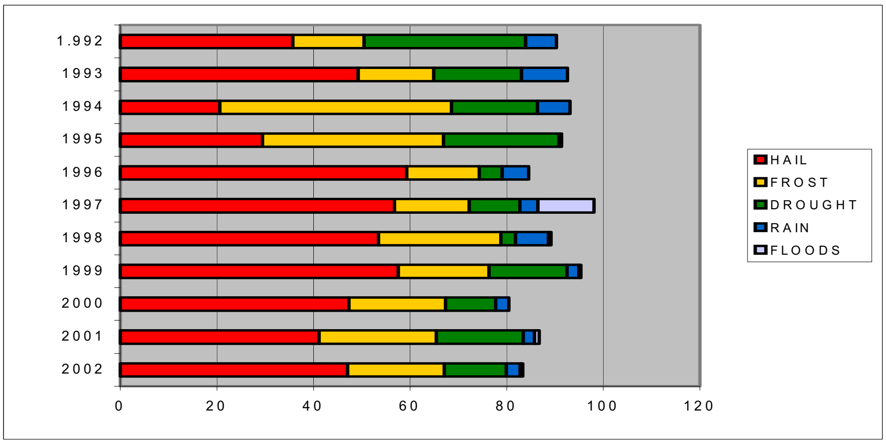


Fig 15.6. *Percentage distribution of the number of losses in agricultural insurance (Agroseguro) 1992-2002. Source: Based on data from Agroseguro (2003)*

The downward trend in the number of claims since 2000 is explained together with fig. 15.7, where there is a decrease in the number of policies since the same year, as owners grouped their own crops and farms under one single policy, albeit this should not be interpreted as a decrease in the volume of insured business.

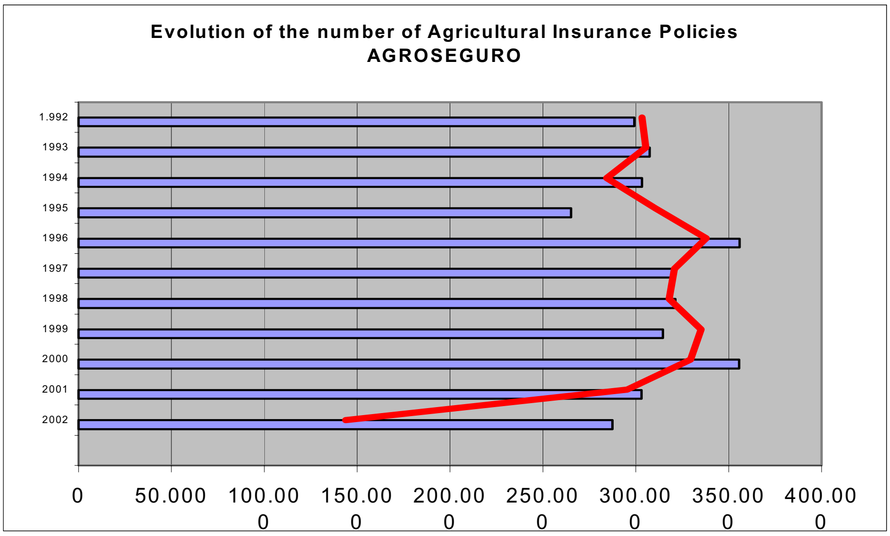


Fig. 15.7. *Source: Based on data from Agroseguro (2003)*

Observing Fig. 15.8, no tendency is identified in the loss experience for hail or frost, causes which were analysed because they were the most representative with regard to volume of premium (53% and 31% in agricultural insurance 2002, respectively), which allows their development to be framed within a scenario of climate change. Rather, the approximation of the loss ratios to 100% in the last few years, from higher values can be interpreted as a response of the adaptation of the insurance system to the needs of the agricultural sector.

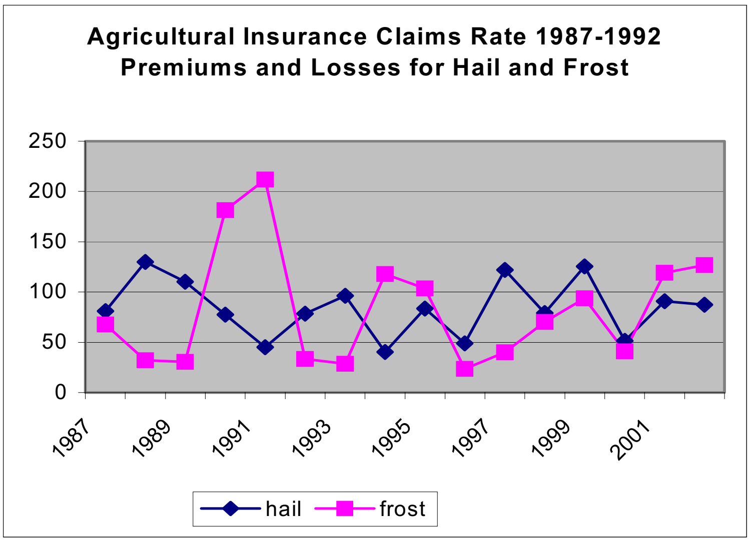


Fig. 15.8. *Source: Based on data provided by Agroseguro (2003).*

15.4. MOST VULNERABLE AREAS

15.4.1. Extraordinary Risks. Indemnities for climate events

The figures shown on the map in figure 4.2 represent the indemnities (updated amounts) paid by the CCS for damage to property by climate events (series 1971-2003), which consist of floods, atypical cyclonic storm, damage by the sea and also, from 1971 to 1986, rain, hail and wind. 80% of these indemnities correspond to floods. It ought to be pointed out that 40% of the indemnities for climate risk considered in the series are jointly concentrated in Valencia and Vizcaya, in almost equal parts.

15.4.2. Main climate and meteorological events in Spain (1980 – 2003, Munich Re)

Table 15.6 now provides details of the main climate and meteorological events on Spanish territory, contained in the Munich Re database since 1980. The amount insured does not appear in all cases, due to a lack of official statistics, and Munich Re therefore bases its calculations on the press and official data and estimates depending on the penetration of the insurance in the affected zone.

15.4.3. Agroseguro maps of climate risk in agricultural insurance

Fig. 15.10 presents the risk map of frost, floods, hail, drought and wind for crops, where the analysis of probability of occurrence (hazard) by the INM is incorporated, along with the loss experience of the agricultural sector according to agricultural regions (for certain hazards, according to municipalities and other subdivisions). Therefore, the distribution of the crops and their sensitivity to these meteorological or climate hazards enables us to differentiate risk areas. In broad terms, the higher risk zones, according to the different phenomena, are:

- frost: interior of the two Northern thirds of the peninsula
- floods: provinces of the Mediterranean coast and specific points on the Northern coast
- hail: North-eastern quadrant
- drought: Southern half and Ebro Valley
- wind: provinces on the Atlantic and Cantabrian coasts, Pyrenees, Southern Mediterranean coast, Zamora, Salamanca and Valladolid.

Fig. 15.11 shows the graph of percentage distribution of communicated individual losses 2000-2003 for agricultural insurance and the main causes – hail and frost, in the provinces with the highest volumes. For hail, Valencia, Lleida, Zaragoza and Castellón, provide the largest level of claims, totalling between 40 and 70% of annual statistics. For frost, the losses are more dispersed throughout the 9 provinces studied, constituting among them all 50 and 65% of annual statistics. For any scenario of climate change with modification in the tendencies of hail and frost, these provinces, particularly Valencia, are the ones whose loss pattern will be most affected, in some cases positively and in others, negatively.

Fig. 15.9. *Indemnities by the CCS. Climatic risks. Damage to property. 1971-2003. Updated figures, in millions of Euros. Based on data from the CCS*

15.5. MAIN ADAPTATION OPTIONS

15.5.1. Involvement

Adaptation to the loss scenario and risk management in a possible climate change, depends on the scope and capacity to react of the insurance institution and of the main actors: the insured party, the insurance market and the state, as well as the degree of involvement of each one of these. This involvement (fig. 15.12) has a double implication: a quantitative one, which refers to the financial capacity and another qualitative one, related to the different ways in which each of these actors can become involved, above all with regard to insurance solutions and alternatives.

The quantitative aspect of the question:

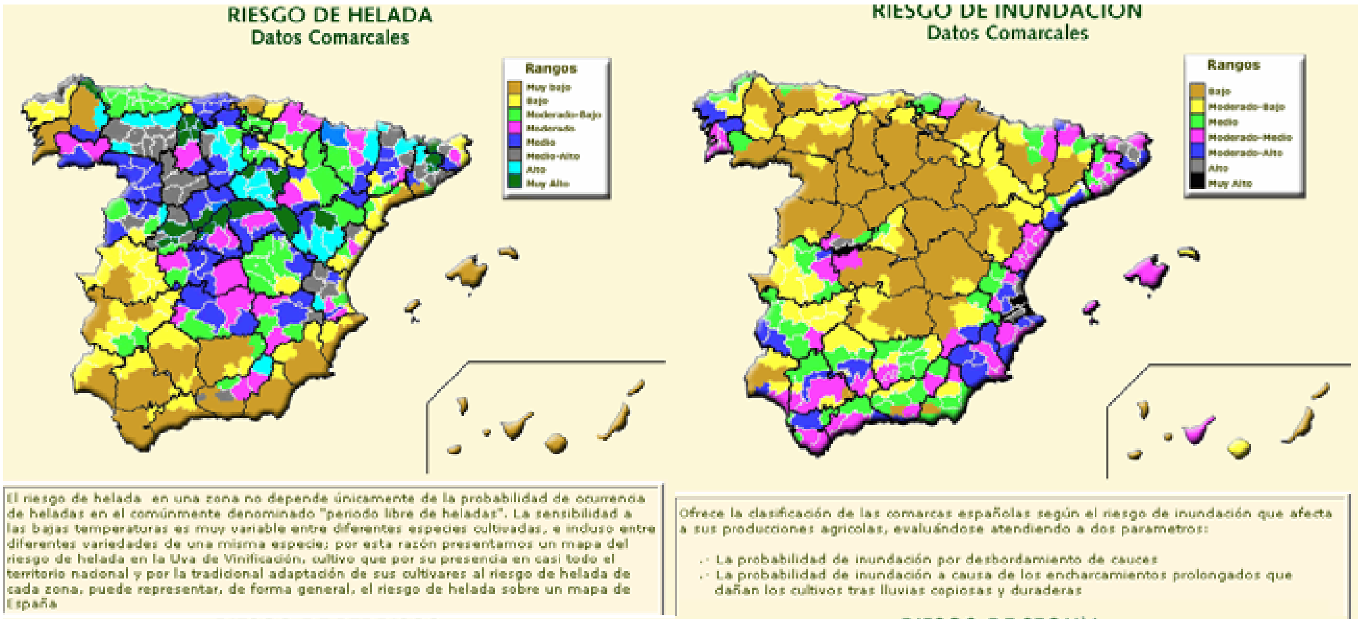
- accessible insurance price for the insured party
- capacity of the insurance and reinsurance market
- capacity of the capital market (alternative transfer of risks)
- capacity of the State (last resort)

The qualitative aspect of the question, that is, the different alternatives for risk finance depending on the involvement of the actors:

- Insured parties: perception of the risk, purchase of cover, preventive measures, participation in the risk (deductibles).
- Insurance market: development of new models of risk management and of new insurance techniques and formulae.
- Capital market: development of finance engineering for the alternative transfer of risks.
- State: adaptation of its participation to the new circumstances, making insurance cover feasible.

Table 15.6. *Insured economic losses in Spain (1980 – 2003) Source: Geo Risks Research Department: Munich Reinsurance Company* 2003. *Amounts in original value, not updated.*

Year	Event	Zone	Economic losses (mill. USD)	Economic losses (mill. USD)
1981	Wind / frost	Guadalquivir Valley	300	Unknown
1981	Drought	Centre and South	1035	Unknown
1982	Heat wave	Barcelona	4	Unknown
1982	Drought	Centre and South	1500	Unknown
1982	Winter storm	Catalonia	350	224
1982	Winter storm	Catalonia	300	224
1982	Floods	Levante	375	Unknown
1983	Floods	Basque Country, Burgos	1250	430
1985	Frost	Spain	350	200
1985	Cold spell	Costa Brava, Valencia	11	Unknown
1985	Drought	South-east	200	Unknown
1986	Winter storm	Spain	100	48
1987	Floods	Valencia, Murcia	1000	185
1987	Storm	Tenerife	32	Unknown
1989	Floods	Málaga	375	Unknown
1989	Storm	Costa Blanca, Ibiza	65	16
1991	Drought	North	1	Unknown
1995	Drought	Andalucía	4500	Unknown
1995	Cold spell	La Rioja	825	65
1995	Storm	Spain	8	Unknown
1996	Floods	Biescas	20	Unknown
1999	Winter storm	Canary Islands	415	Unknown
1999	Winter storm	Bilbao, Asturias (Martin)	100	24
1999	Drought	Extremadura, Castilla la Mancha	3200	
2001	Hail	Valencia	50	Unknown
2001	Storm	Catalonia, Baleares	6	Unknown
2002	Floods	South	100	Unknown
2003	Storm	San Sebastián, Costa Dorada	1	Unknown
2003	Storm	Aragón, Catalonia	10	Unknown



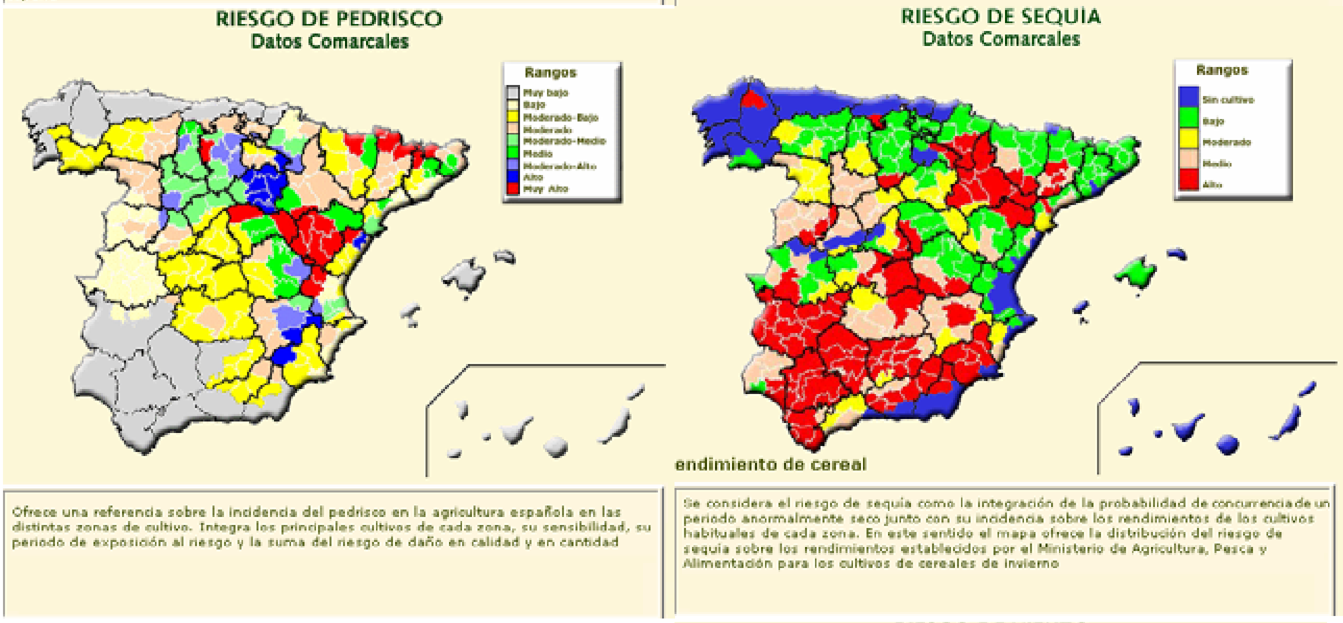


Fig. 15.10 *Agroseguro maps of risk zones for frost, floods, hail, drought and wind in agricultural insurance. Source: Agroseguro (2003)*

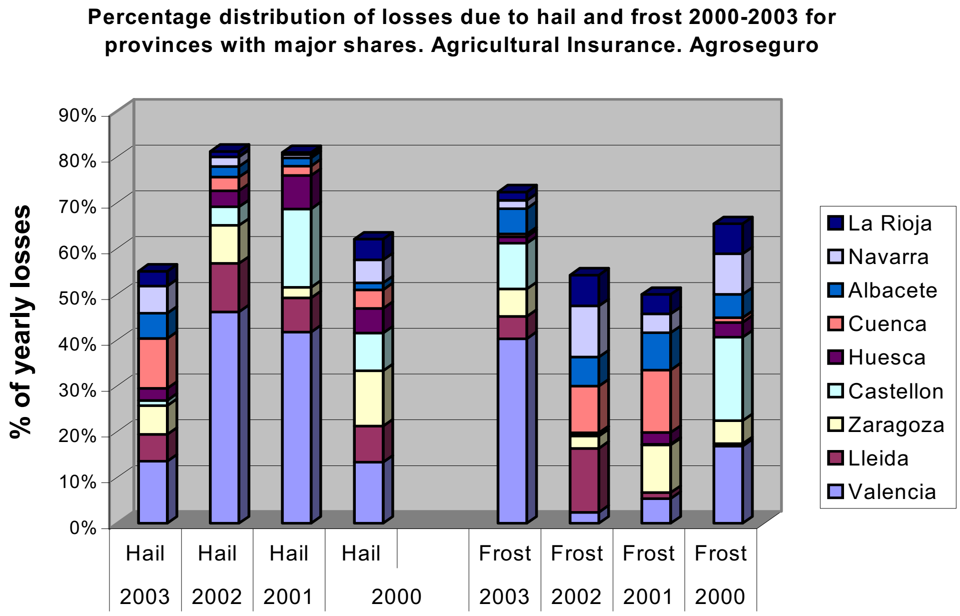


Fig. 15.11. *Source: Based on data from 2003. Agroseguro Report (2003)*

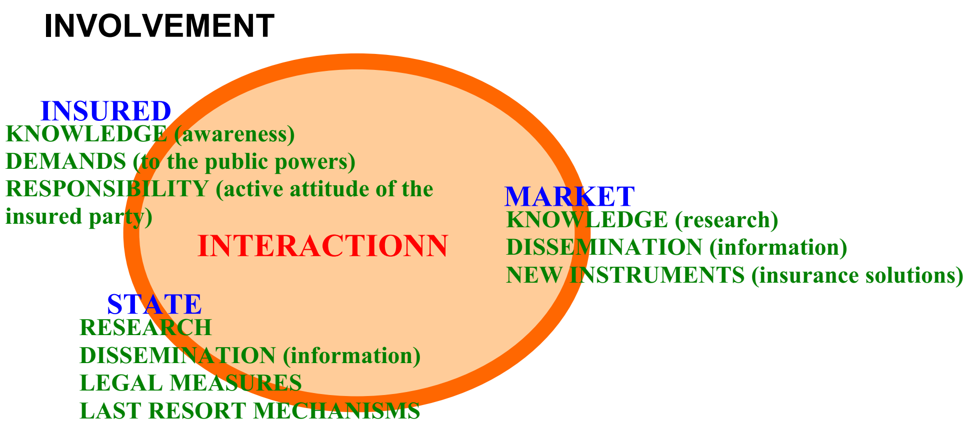


Fig. 15.12. *Interactions among actors involved in insurance solutions and alternatives*

15.5.2. Promotion and information on the insurance

A severe claims scenario resulting from climate change will force a profound change with regard to how the insurance institution will be perceived from the point of view of the different actors (insured party, market, State). A new insurance culture will probably take over, in accordance with the new loss situation, in which some of the fundaments of insurance and other aspects that will be seen to be crucial will be clearly put in practice in relation to the feasibility of insurance solutions; these will require promotion and information actions in order to gain social awareness. In this sense, certain fundamental points must be underlined:

- Insurance as a responsible attitude of the potential affected parties (active participation), involvement in the protection of their lives and property.
- Insurance as an instrument of transfer of risks (possibility of recovery/financing of the loss suffered).
- Insurance as a channel of solidarity among potentially affected parties (mututalisation and distribution of the risk in order to make the cover viable).
- Insurance as a preventive mechanism) application of deductibles, reductions in premium, etc., in order to promote the mitigation of risks).

15.5.3. Dissemination of the prevention culture

Prevention must be a fundamental element in any integral strategy for dealing with risks of a climate nature. There is a need to create a new awareness, a new way of considering and dealing with a problem and, in short, a new prevention culture, due to its implications from different perspectives:

- Prevention as a social value (stability and cohesion factor)
- Prevention as a political imperative (as an objective of general interest)
- Prevention as economic profitability (investment in the future)
- Prevention as a stimulus for research (in knowledge, mitigation, treatment)
- Prevention as a pillar of management of climate risks

Within the specific technical insurance tools, we will now value the possibilities existing in order for the sector to bear a high volume of risks, that is to say, what methods of risk transfer can be considered in order to attempt to reduce the impact of climate change in the insurance sector?.

15.5.4. Actuarial methods

These are the classical methods, typical of the actuarial sciences applied by the insurance companies in order to mitigate and correct the impact of a heavy loss, among which we can highlight:

- Increased rates
- Cancellation of policies (improvement of the portfolio mix)
- Indemnity Limits
- Increased deductibles / franchises
- Improvements in the technical underwriting
- Enhanced loss adjustment

History has shown that, following a serious event the insurance companies tend to raise their premium drastically, as happened after hurricane Andrew in 1992 in the state of Florida (USA). Following a quiet spell, new insufficient rates are set in relation to the assumed risk, whose theoretical level of probability does not vary, in principle (Matthews *et al*. 1999).

15.5.5. Reinsurance

The basic objective of the transfer of risk to reinsurance is to reduce the liability of the direct insurer, in an attempt to avoid future unknown deviations that can become severely aggravated in the case of natural events. The reinsurer reduces the potential losses of the insured on taking on part of the risk, although the former seeks a balance in his portfolio by means of the geographical dispersion of the business assumed (different insurance companies in different countries) and, particularly, with regard to situations of high losses which are difficult to control, like losses with large return periods.

It must be pointed out that beyond the mere transfer of risk, reinsurance, due to its vast experience in dealing with the hazards of nature, has traditionally offered support to the sector on making numerous profound analyses of markets and large losses, apart from providing consultation in relation to the diverse options for adaptation to the new risks. Table 15.7 shows the rapid positive evolution (2000-2002) of the relevance of reinsurance as a support to direct insurance.

Table 15.7. *Worldwide Direct Insurance and Reinsurance Premiums. Source: Partner Re 2004*

(in Millions of Euros)	**Direct**	**Reinsurance**	**% Cession**
North America	479.300	54.371	11
Europe	289.420	40.987	14
Japan	48.516	1.673	3
Asia	76.119	9.201	12
Rest of the World	19.239	8.365	43
Total 2002	912.594	117.107	13
Total 2000	761.192	86.157	11
% Inc Cession 00-02	20%	34%	2

Reinsurance is not the only way to adapt to climate change, but is rather the traditional option, and it was in the 90’s, when what is known as ART (Alternative Risk transfer) was established, coming from the purely financial sector..

15.5.6. ART (Alternative Risk Transfer)

The ART solutions could be considered to be finance products aimed at solving problems related to the transfer of specific risks, more than the use of these as a product of standard reference. These solutions act as a complement to the traditional reinsurance methods in order to optimise the retention of the risk, to reduce the volatility of the revenue throughout time and to obtain new sources of financing capable of assuming business.

Through the different forms of risk transfer presented, the insurance sector shows its capacity to adapt to catastrophic events. The problem is knowing if it is fast enough, and more so, the degree of acceptation of these alternative methods within such a traditional sector.

In short, the ART products were designed to limit the risk in any sector of losses of a potentially unforeseeable amount and erratic recurrence, with the possibility of a scenario of climate change. This transfer of risks can be made by insurance companies, reinsurance companies or by the insured himself, who can go to the finance market and acquire a cat bond, as already happens in some companies of the energy sector.

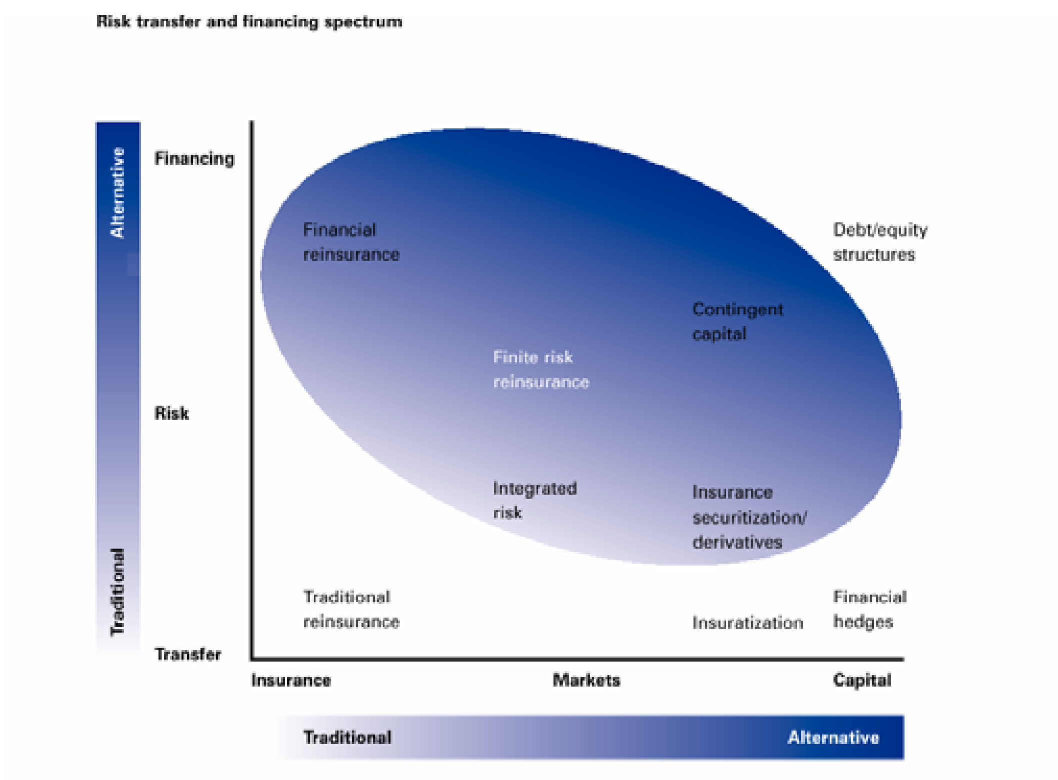


***Fig. 15.13**. Risk Transfer and Financial Spectrum. Source: Munich Reinsurance Company 2000*

We will now give a brief description of the different alternative solutions that can help the insurance sector to adapt to the consequences of possible climate change (table 5.3):

- Methods of risk finance (Financial Reinsurance)
- Capital markets
  - Climate derivatives (Options / Swaps): they function in a very similar way to their homonyms in the capital sector, although in this case they provide protection (hedge) against climate variations (temperature, rains, droughts,...)
  - Bonds (Cat Bonds): they function in a similar way to the more common bonds, but the payment of interest and of the nominal are linked to a meteorological index.

Recently, more alternative methods for the transfer of risks have appeared, as can be seen in figure 15.13, although the ones already described can be considered as the most commonly used ones. In spite of all, and as we are told by the GAO (United States General Accounting Office) and the Swiss Reinsurance Company, the number of Catastrophe Bonds is only between 2.5 and 3 % of worldwide catastrophe cover.

15.6. REPERCUSSIONS IN OTHER SECTORS OR AREAS

15.6.1. Insurance and Reinsurance

The direct effect that a climate change with an increase in losses offers to the sector is obviously a negative one. The technical calculation of the premium that an insurance company has to charge in order to face possible losses is based on past results and claims. If the climate change leads to results of different frequency and/or intensity which are unexpected or unknown, many insurance companies may find themselves in a situation of insolvency. In the case of Spain and for the private insurance market, the existence of CCS and Agroseguro, constitutes a good backup, although this does not exempt any of the aforementioned “pools” from considering the scenarios of climate change.

With regard to reinsurance, due to its backup role in the sector, it will be directly involved, with greater or lesser losses, in the effects of any possible climate change. And more so if we take into account that it can suffer the impact of the accumulation of losses from different insurance companies in the same affected zone. The incorrect and/or incomplete management of the location of the risks making up a portfolio, whether from the point of view of the insurer or of the reinsurer, could be disastrous in the event of catastrophic losses, on being unaware of their extent and total amount.

15.6.2. Society in general

Although the implications of the possible effects of climate change on the insurance sector in society are not so evident, it is possible to study what has happened in parts of the world with a higher incidence of climate events. As indicated by Swiss Re in a study in the year 2000 (Beder 2001) around 650 United States insurance companies claimed bankruptcy from 1969 to 1998 as a result of natural disasters.

The situation of bankruptcy in an insurance market not only causes a decrease in competition in the sector, a rise in insurance prices, distrust by the insured parties and a direct effect on the Consumer Price Index of these countries, but can also lead to a situation in which insurance cover cannot be purchased. This is what happens in certain zones highly exposed to natural hazards in the USA, where the population has serious problems to find insurance for their properties.

15.6.3. State

As a last resort, the State will be responsible for controlling the insurance offer for these covers, or who will end up providing this protection. In Spain, this is mostly solved due to the existence of the CCS, although they are not responsible for all the possible loss events. There is always room for joint solutions with public insurance complemented by the participation of the private sector and the State. It must also be taken into account that many of the infrastructures belonging to governments have, in many cases, a “self-insurance” system, and in this case, they will be equally affected. In the case of a natural disaster, we must not only consider the direct loss, but also the costs of the reconstruction-recovery.

15.6.4. Bank

At present, finance companies and especially banks are starting to consider the potential of climate change when evaluating the profitability of investments or developing new products (World Bank 1999), which can be considered a new niche in the market and also a new form of competition. What is clear is that in recent years the banking world has been capable of adapting to new and more complicated situations, creating new products and services. A new series of products has already been created, from investment funds based on environmental parameters to sophisticated derivatives designed to correct deviations in relation to meteorological risks.

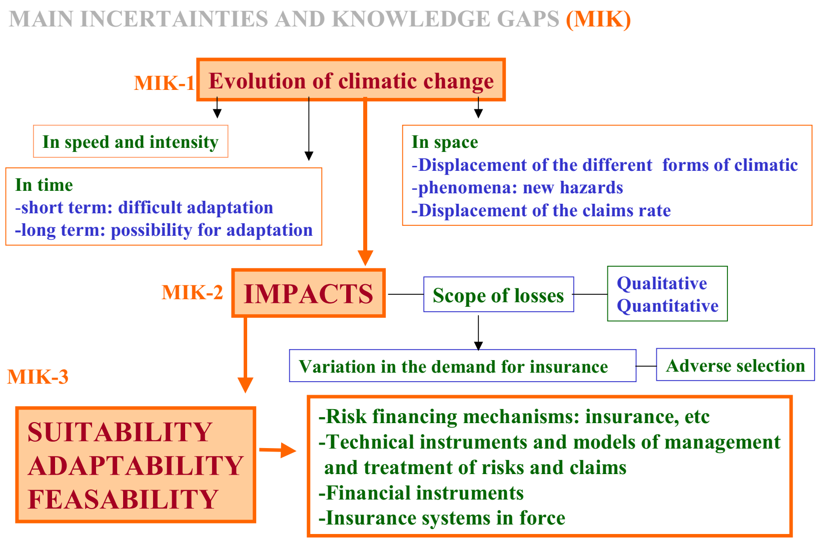
15.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

The main uncertainties and fundamental questions related to the effects of climate change in the insurance sector affect three different levels (table 15.8):

15.7.1. Evolution of climate change

Of all the situations that could be considered possible, it is not certain which one will materialise, what degree of climate variation it will have and how fast it will arrive; this depends on the region, area and zone that is considered. There will logically be more time to react if the period in which the change occurs is longer, and the variation is smaller. The geographic displacement of the different forms of climate phenomena and, therefore, the displacement of losses, is another uncertainty to be considered.

Table 15.8. *Main uncertainties and knowledge gaps*



15.7.2. Impacts and effects that can be expected

The impact, the extent of the damage and the intensity of the losses will depend on the behaviour of the possible climate change and on the vulnerability of the areas affected (exposure to risk, population and values exposed, concentration...). Qualitative, intangible losses, such as those that can affect the social structure, the political system and the culture of a population, are not contexts in which insurance has an important role to play. A quantitatively very high loss may mean, as a consequence, losses in the sense indicated, but it may also mean a qualitative alteration in the way the insurance is conceived and in its modalities and applications.

It can be predicted that the variation in the extent and intensity of the losses (uncertainty) will, directly affect the variation in the demand for insurance. The problem with adverse selection (that only those with the highest levels of risk can obtain insurance) will continue to be latent in the cover of disasters, and nature and scope of the cover system adopted will depend to a great extent, on the way this is dealt with.

15.7.3. Suitability, adaptability, and feasibility of the insurance institution

On the first point (15.7.1), depends the resolution of the suitability, adaptability, and feasibility of the instruments and systems of cover with regard to the scenarios in which they occur, which leads to the question of what margin there will be to manoeuvre, as well as the capacity to respond of the organisations, companies, institutions and organisms that participate or may participate in insurance solutions in relation to these scenarios.

15.8. DETECTION OF THE CHANGE

This is a question of identifying proxys that can be used to indicate a possible climate change in a specific manner in the insurance sector:

15.8.1. Variation in claims

- In key lines of business:
  - **Storms**: The aforementioned increase in losses due to storms in the insurance sector both in Spanish direct insurance and in the CCS statistics, can be related to the increase in exposures and insurance penetration. However, it is a factor to be taken into consideration.
  - **Floods**: The same as for storms.
  - **Frost, drought, hail**: these are lines of business which are traditionally related to agricultural risks. Due to the prolonged statistics on hail cover for this type of risks (1940-2003), it may be possible to identify a pattern of incidence of extreme temperatures in summer with hailstorms.

- Other lines of business: The current figures are not clear enough in sectors like health care, personal accidents or transport, which means to say that there is no clear correlation between these lines of business and the evolution of the present climate.

15.8.2. Insufficiency of prices

The calculation of the insurance price is based on past experience. Recently, prices charged for cover of natural disasters or natural events have clearly been insufficient to deal with the large losses, which could not be recovered in the predicted amount of years, before another great event took place, of similar or higher amounts.

This happens because it is very difficult to consider the potential losses of an extreme event, especially when its return period can vary, like, for instance, a possible climate change. Thus, for a heat wave like the one that occurred in summer 2003 in Europe, a return period of 450 years (Munich Re 2004) was considered. In the following decades, perhaps we will see if this parameter has been reduced with regard to the danger of high temperatures due to a shorter return period.

15.8.3. Reaction of the finance sectors towards profitable sectors

The reaction of the finance institutions may involve the search and continuous creation and growth of adapted finance products, mainly financial derivatives and formulae for the mitigation or adaptation of any industry in this sense. They also adapt existing products, such as mortgages, in order to deal with the risks caused by climate in this new scenario.

15.9. IMPLICATIONS FOR POLICIES

From the insurance sector point of view, we will now enumerate the actions considered to be necessary and positive, along with the organisms that should promote them, in order for the insurance activity to be developed in Spain in an environment more adapted to the foreseeable consequences of climate change:

- Review of the Basic Regulations of Building and Design in order to adapt all types of old and new structures to more extreme and/or more frequent manifestations of climate hazards. Civil Works Office.
- Land Planning and Uses in accordance with the danger level established in each area for climate phenomena. Environment Office, Housing Office.
- Promotion of education in prevention from primary school. Education Office.
- Promotion of prevention. Civil Defence. Home Office
- Financing of research aimed at all areas affected by the climate. Science and Technology Ministry. Health Office.
- Adaptation of insurance cover and International Accounting Regulations (IAR) Ministry of Treasury.
- Feasibility analysis of agricultural policy. Agriculture Office.

For the better development of these measures, once they have been analysed and implemented on a national level, a follow-up must be made in the regional context.

15.10. MAIN RESEARCH NEEDS

Research needs will be distinguished when these are related to the hazard of natural phenomena, the vulnerability and economic value of the insurable properties.

15.10.1. Hazard

This refers to improved knowledge of the phenomena, so that signs of climate change can be detected.

- Adaptation of formats (for instance, new technologies) and deadlines of the data deliverance on meteorological phenomena for the needs of the insurance sector.
- Explanation of the scenarios handled by the IPCC, which are specific to Spain, for their suitable use in all fields of study.
- Standardisation meteorological and climate variables measurements, as well as of procedures with European countries.

15.10.2. Vulnerability

- Experimental studies of crops and structures vulnerability in the different geographical areas to the main meteorological and climate phenomena in their most extreme manifestations.
- Statistics that are detailed and prolonged over time related to data on claims for the Spanish insurance market, both per areas and per catastrophic events, to help to detect climate change.

15.10.3. Economic value

- Updated statistics on the insurance penetration in Spain according to types of risk, specified in insured values.
- Updated statistics on the real estate pool (census), as a potential insurance market.

The combination of hazard, vulnerability and economic values exposed or not, together with the insurance types, in order to recreate historic scenarios and specific probabilistics for the insurance sector, has led to *catastrophe models (cat models)*, very widespread throughout markets outside Spain. In some cases, the influence of medium and long-term climate change is included in order to generate databases of stochastic events. Cat Models are not used within the Spanish insurance market, meaning that the insurance companies will not comply with the standards of the Rating Agencies to get a sound qualification. This is very important for shareholders, stock markets and international competition.

15.10.4. Monitoring

This analysis of insurance market evolution during last decades, trying to identify past effects and guess future reactions to climate change, should not finish here. The creation of a Monitoring Observatory of the insurance sector behaviour is proposed in a foundational framework, including entities such as CCS and Agroseguro, as well as insurance and reinsurance market participants, both national and international.

15.10.5. Conclusions

15.10.5.1. Statistical data

Having analysed the available statistics, we can reach conclusions in relation to each data set:

Loss experience in the DGSFP non-life lines of business (1967-2002)

The global loss experience from 1967 to 1981 presents an average of 57%, whereas from 1982 to 2002 this was 71% (table 2.1). It has been argued that this increase in the average by over 10 points between the two periods is due to the reduction in the number of companies operating in the sector, which began to compete fiercely, reducing rates while maintaining a similar loss rate. Although we cannot fully rule out their influence, these data do not allow us to consider climate change in a clear and obvious way among the determinant factors of this evolution, and less so, to distinguish their degree of participation therein.

CCS floods compensation (1971-2002)

The ascending tendency in the series for the period analysed (table 3.4) has been attributed to the increase in the insurance penetration into a society with more insurance culture and to the increase in both exposures and insured values. Without totally ruling out its influence, no clearly identifiable signs have been detected to indicate that climate change has left its mark –or to what degree- in the tendency presented for this period. The Mediterranean coast (mainly Valencia) and the Basque Country (Vizcaya) concentrate a high percentage of claims due to climate risks and could be considered as zones that are sensitive to the consequences of climate warming in the future.

Munich Re data base of climate and meteorological events (1980-2003)

The economic costs of the events registered by Munich Re for just over two decades rise in the second half of the period. Therefore, the tendency, described in the previous two points, towards an increase in events and losses is yet again sustained. The coastal provinces of the Mediterranean form part of several loss scenarios, and they are then profiled as a more susceptible zone with regard to a change in climate and meteorological parameters.

Loss experience in Agricultural Insurance (Agroseguro 1967-2002)

The agricultural insurance scheme has undergone continuous transformations in an attempt to compensate for results and to cover the highest number possible of crops by means of a varied range of covers. Thus, statistics do not allow us to analyse the loss rate in a homogenous way. However, the geographical distribution of the loss experience is the reference of the zones that, if a significant deviation were to occur in the climate parameters, would present a modification in agricultural production, in a positive sense in some cases (lower number of frost events, which are also less intense), or negative in others (increase in the number of storms accompanied by hail). An adaptation of farming techniques will continue to be imposed. In general terms, it can be said that the Eastern half of the peninsula, due to the high hazard level of climate and meteorological phenomena, and to the concentration of crops sensitive to these variables, has been confirmed as the most delicate zone, with particular incidence in the province of Valencia.

To summarise, no clear signs have been detected of the effects of climate change in the insurance sector in Spain, the trajectory of which is described by the permanent evolution of the market in search of better formulae, incorporating the influence of the socioeconomic development characteristics of each era. It is therefore impossible to compare the annual or multi-annual statistics homogenously. However, the tendency observed in other markets towards an increase in the number of catastrophic events, the intensity of these and their economic and insured cost, is also occurring in Spain.

> "The development of insured losses since 1970 reveals a clear trend towards higher losses. This rise can, for the most part, be explained by economic, demographic and geographical factors. Specifically in industrialised countries, there was a demonstrable and rapid rise during this period in insured values (…). Greater vulnerability to losses is to be expected against the backdrop of a potential shift in climate zones caused by climate change".

Swiss Re (2004b)

15.10.5.2. The present and future of Spanish insurance market

In Spain, the insurance of phenomena derived from a possible climate change is consolidated through the CCS (accidents and property) and Agroseguro (crops and livestock).

The CCS, which has accumulated much experience since it was set up (1954), has handled so far a loss rate within a context of moderate natural hazard level with regard to the covered phenomena. Its excellent management in synch with the private insurance market, and backup by the State as last resort, means that they constitute an exemplary system worldwide, based on solidarity and the mutualisation of risks.

With regard to Agroseguro, set up in 1980 and based on a series of enriching antecedents since the beginning of the century, both positive and negative, which have served to design an optimum and dynamic system in accordance with a sustainable and modern agricultural policy, also faces the difficult challenge every year, together with the private insurance market, of adapting actuarial techniques to an activity which is in a clear process of technological development.

The permanence and vast experience of the CCS and Agroseguro systems would seem to indicate that the insurance sector in Spain is prepared to absorb variations in losses derived from short and medium-term climate change. Thinking of the long-term, and depending on the scenario of climate change that may occur, the suitable combination of certain insurance techniques and agile financial tools with an international reinsurance system that is heedful of the requirements of every moment, and with state participation sensitive to any needs for backup, may lead to solid and imaginative insurance solutions at accessible prices for society.

Fig. 15.14 relates in a qualitative (A) way the sensitivity of the insurance lines of business that could be affected by climate change, with each meteorological hazard (wind, precipitations and temperature), the occurrence patterns of which might vary. For these same lines of business, graph B shows, also qualitatively, the insured interests that are most involved in each one of these.

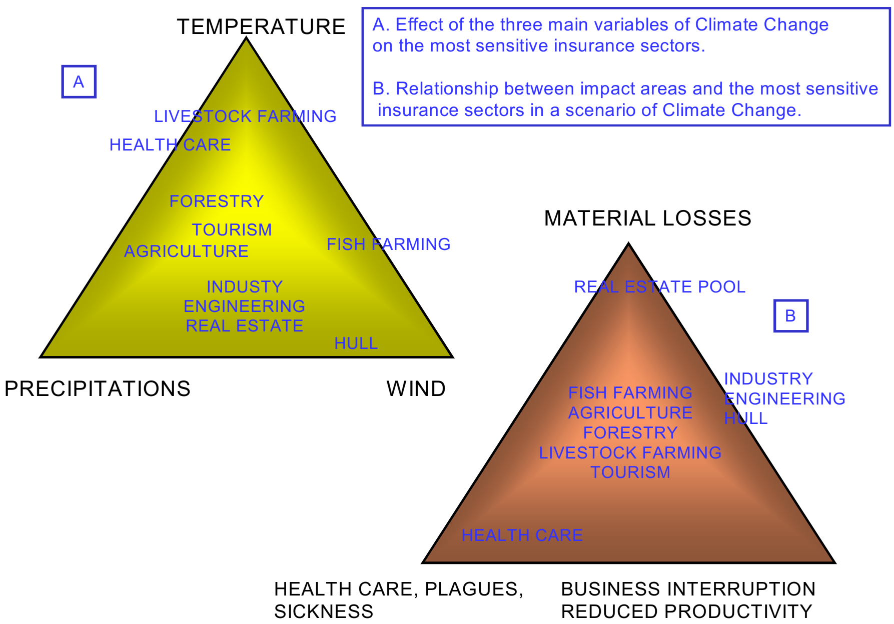


Fig. 15.14. *A) Effect of main variables in the insurance sector; B) Relationship between sensitive insurance sectors*

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16. IMPACTS ON HUMAN HEALTH

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ABSTRACT

The interactions between climate change and human health are multiple and complex. They could, however, be summarised as following: a) changes in morbidity and mortality in relation to temperature; b) effects upon health of extreme meteorological events (tornadoes, storms, hurricanes, and extreme precipitation; c) Atmospheric pollution and an increase in the associated effects on health; d) Diseases transmitted by food and water and e) Diseases transmitted by infectious vectors and by rodents (Patz *et al* 2000).
The limited size of the chapter requires us to deal with those factors that we believe are of greatest relevance in our country.

The extremely high temperatures recorded in Central Europe during the summer of 2003 and in the North and East of Spain highlighted the effects of high temperatures on morbidity and mortality. This chapter analyses the main impacts of heat waves, fundamentally, and of cold spells. The socioeconomic factors influencing this excessive mortality are considered, and the measures that ought to be taken into account in prevention plans are dealt with. The need to streamline morbidity and mortality records in Spain is emphasised, as are the policies necessary to minimise the impacts upon health of extreme temperature events.

Atmospheric pollution constitutes an environmental risk with negative consequences for health. This risk has been studied for years, and more knowledge now exists as a result of research in recent years. Emissions into the atmosphere related to climate change could exacerbate the effects of air pollution upon the health of citizens, not only directly, through the impact of meteorological phenomena, but also immediately, through the direct effects of pollutants upon health. However, for too long, efforts throughout the world have attempted to deal with both problems separately. Indeed, it has often been believed that the benefits of climate protection for health would be felt in the long term. To the contrary, what has been seen in recent years is that actions aimed at reducing emissions of pollutant gasses would produce beneficial effects in the short term due to the reduced impact of atmospheric pollutants on citizens' health. In the section dealing with atmospheric pollution, the sources and main pollutants are described, the results of epidemiological and toxicological studies carried out in Spain and abroad are reviewed, and the possible risks of the pollutants most related to climate change, such as ozone or fine particles, are presented. Taking into consideration the main uncertainties and knowledge gaps in relation to the subject at the present time, we considered the main implications for policies related to the theme in Spain, along with research needs. In this sense, both from the point of view of surveillance and research, the establishment of an epidemiological system for the observation of the effects of atmospheric pollution is believed to be necessary.

We could expect this type of diseases to be increased by climate change in Spain, due to its proximity to the African continent, and to the fact that it is a place of obligatory transit for migrating birds and people, and to its climatic conditions –close to areas in which the transmission of vector-borne diseases exists. The possible risk lies in the geographic spread of pre-established vectors or in the import and establishment of subtropical vectors adapted to survival in cooler, drier climates. Hypothetically, the vector-borne diseases susceptible to influence by climate change in Spain would be those transmitted by diptera, for example, dengue, West Nile encephalitis, Rift valley fever, malaria and leishmaniasis; the ones transmitted by ticks, such as Crimean-Congo haemorrhagic fever, tick-borne encephalitis, Lyme borreliosis, Boutonneuse fever and endemic relapsing fever; and those transmitted by rodents. But the greatest and most feasible threat would involve the establishment of the mosquito *Aedes albopictus*, which is capable of transmitting viral diseases such as West Nile or dengue. But for the establishment of authentic endemic areas, a combination of several factors is needed, such as the mass and simultaneous influx of animal or human reservoirs and the deterioration of social and health conditions and of the Public Health services.

16.1. INTRODUCTION

16.1.1. Extreme temperatures

16.1.1.1. Relationship between temperature and morbidity and mortality

Morbidity and mortality is known to present seasonal dynamics characterised by a winter maximum and a summer peak of lesser magnitude, which is, however, sometimes more intense from the point of view of its effects on health than the excess itself of winter morbidity and mortality (Mackenbach *et al* 1992, Alderson 1985). The results of numerous research projects indicate that the relationship between temperature and morbidity and mortality is usually “U” or “V”-shaped, with a minimum incidence temperature that varies from one place to another (Kunst *et al* 1993, Sáez *et al* 1995, Ballester *et al* 1997, Alberdi *et al* 1998) and which probably depends on the adaptation of the population to the temperature range to which it is exposed (Curreiro *et al* 2002, García-Herrera *et al* 2004). Wintertime excess mortality is mainly accounted for by respiratory and circulatory disorders, whereas the latter are also related to increases in summertime mortality (Alberdi and Díaz 1997). The older age groups are the ones that most contribute to this excessive morbidity and mortality (Alberdi *et al* 1998, Ballester *et al* 2003). With regard to temporal distribution, the effects of heat are short term (1-3 days), whereas the effects of cold usually occur between one and two weeks after the thermal extreme (Alberdi *et al* 1998, Braga *et al* 2001), which is coherent with the underlying biological mechanisms (Huynen *et al* 2001, Havenit 2002). An example of this is seen in the fact that the mean daily mortality due to all causes except accidents (CIE IX 1-799) registered in the Comunidad de Madrid (Madrid regional autonomy) from 1986 to 1992, in relation to maximum daily temperature, presents a “V”-shaped relationship, with a maximum daily temperature of minimum mortality of 30.8 ºC (Díaz and López 2003)

16.1.1.2. Definition of heat wave and cold spells

From the point of view of effects upon health, there is no uniform criterion for the definition of a heat wave (W.H.O 2004) or a cold spell. In the case of heat waves, some authors base their definition of extremes on an established threshold which depends on both maximum and minimum air temperature and on mean daily values, while others make use of indexes (apparent temperature, etc.) that consider relative air humidity (Nakai *et al* 1999, Smoyer 1998, Jendritzky *et al* 2000) or meteorological situations at synoptic scale (Kalkstein 1991).

Recently, different studies on the Iberian Peninsula have established the existence of a maximum daily temperature above which a sharp increase in mortality is observed. In relation to Madrid, this “triggering effect in mortality” maximum daily temperature is 36.5 ºC (Díaz *et al* 2002a), 41ºC for Seville (Díaz *et al* 2002b), 33.5 ºC for Lisbon (García-Herrera *et al* 2004) (figure 16.1) and 30,3 ºC for Barcelona. In all these places, this temperature coincides with the 95 percentile of the series of maximum daily temperatures during the summertime period (June – September) from 1991 to 2002. Given that one single day with a temperature above this threshold significantly affects mortality, it has been proposed that a heat wave be defined as the period in which maximum daily temperature exceeds the 95 percentile of the series of maximum daily temperatures in the June - September period. The duration of the heat wave will be determined by the number of consecutive days in which this threshold is surpassed.

In the case of cold waves, behaviour analogous to that of the heat wave has been observed, which is exacerbated by the fact that the effect of cold is much more intense in the long term, and it is therefore more complicated to establish a cause-effect relationship (Braga *et al* 2001). There is, however, a maximum daily temperature below which mortality rises sharply. In the case of Madrid, this maximum daily temperature, around 6ºC, coincides with the percentile 5 of the series of maximum daily temperatures during the winter period (November –March) (Díaz *et al* 2004a).

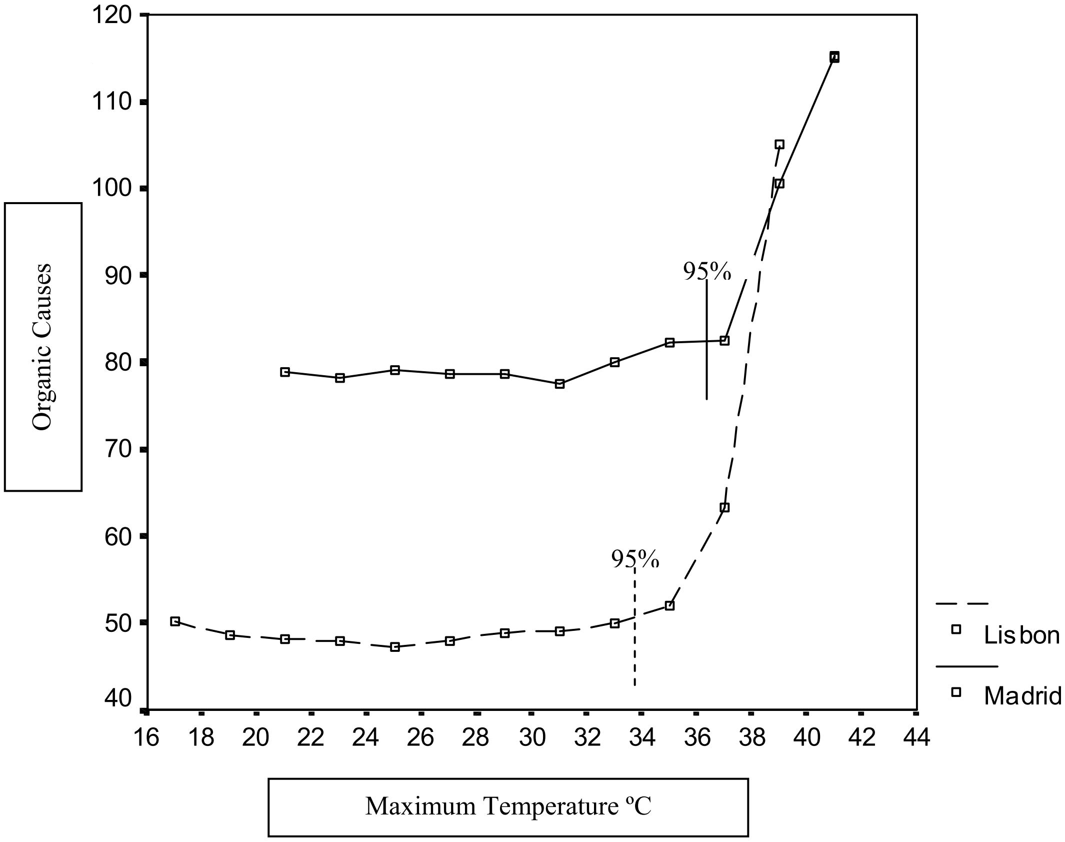


Fig. 16.1. *Mortality threshold temperature for the cities of Madrid and Lisbon. Threshold temperature is set at 95% for the series of maximum daily temperatures in the June-September period.*

Which means to say, that there is a relationship between mortality and temperature which is exacerbated in the event of thermal extremes, cold spells or heat waves. Indeed, when maximum temperature is above the 95 percentile or below the 5 percentile the magnitude of the impact becomes greater.

16.1.2. Air pollution

16.1.2.1. Air pollution and human health

Air pollution is understood to be the presence in the air of substances and forms of energy altering the quality thereof, in such a way as to pose risks or to cause harm or serious discomfort to people or property of any kind. In the field of public health, air pollution is a well-known phenomenon which has been long studied, and is of great importance in the modern world, basically due to a series of episodes that took place in the industrialised countries during the first half of the XX century.

In recent years, many studies carried out in different cities have found that even below the levels of air quality considered as safe, increased air pollution is considered to be harmful for human health. A study carried out in France, Switzerland and Austria indicates that 6% of mortality and a large number of new cases of respiratory disorders in these countries can be attributed to air pollution. Half of this impact is due to the pollution caused by motor vehicles (Künzli *et al*. 2000).

The World Health Organisation (WHO 2003) considers air pollution to be one of the most pressing world health priorities. A recent report estimated that air pollution is responsible for 1.4% of all deaths in the world (Cohen *et al* 2003). There is also growing concern about the risk of agents for which no satisfactory evaluation exists, such as Polycyclical Aromatic Hydrocarbons (PAH). In short, large sectors of the population are exposed to air pollutants, with possible negative consequences for health.

16.1.2.2. Air pollutants and their sources

Air pollutants, usually measured in the urban atmosphere, come from mobile sources (traffic) and stationary sources of combustion (industries, heating and waste disposal processes). A distinction is made between primary and secondary pollutants. The former are the ones coming directly from the sources of emission. Secondary pollutants are produced by the transformation and by the chemical and physical reactions that primary pollutants are subjected to inside the atmosphere, this involving, above all, photochemical pollution and the acidification of the environment. The characteristics of the main chemical pollutants and the sources of these are summarised in table 16.1.

Table 16.1. *Description of the main chemical air pollutants*

Pollutant	Formation	Physical state	Sources
Particles in suspension (PM): PM_{10}, Black smoke.	Primary and secondary	Solid, liquid	Vehicles Industrial processes Tobacco smoke
Sulphur dioxide (SO_2)	Primary	Gas	Industrial processes Vehicles
Nitrogen dioxide (NO_2)	Primary and secondary	Gas	Vehicles Gas heaters and cookers
Carbon monoxide (CO)	Primary	Gas	Vehicles Tobacco smoke Indoor combustions
Volatile organic compounds (VOCs)	Primary, secondary	Gas	Vehicles, industry, tobacco smoke Indoor combustions
Lead (Pb)	Primary	Solid (fine particles)	Vehicles, industry
Ozone (O_3)	Secondary	Gas	Vehicles (secondary to NO_x photo-oxidation and volatile organic compounds)

PM_{10}: particles with an aerodinamic diameter of less than 10 μm
NO_x: nitrogen oxides

16.1.2.3. Studies of the effects of air pollution on health

Interpretation of the effects of air pollution upon health is based on two types of studies, toxicological and epidemiological, which are considered to be complementary.

One of the most commonly used epidemiological designs used involves *time series*. These studies analyse variations in time of the exposure and population health indicators (number of deaths, hospital admissions, etc.). On analysing the population in different periods of time (generally day-to-day), many of the variables that, individually, could act as factors of confusion (smoking habit, age, sex, occupation, etc.) remain stable in the same population and lose their power for confounding (Schwartz *et al* 1996).

In recent years, different multicentre projects have been carried out, based on standardised analysis criteria for the study of the different aspects of the air pollution-health relationship. In

Europe, the APHEA project (Air Pollution and Health: a European Assessment) (Katsouyanni *et al* 1996) and in the United States the NMMAPS study (Nacional Mortality and Morbidity Air Pollution Study) (Samet *et al*. 2000a; 2000b) are among the studies that have most contributed to knowledge of the acute impact of pollution upon health. In France (Quennel *et al* 1999), and Italy (Biggeri *et al* 2001) national multicentre studies have been carried out, assessing the impacts of pollution, considering environmental, health and social characteristics. In Spain, the EMECAS project is carrying out a study of the impact of air pollution and involves 16 cities (EMECAM 1999, Sáez *et al* 2002, Ballester *et al* 2003).

Although fewer than studies of temporal series, there are several cohort studies of the impact of air pollution on health. The most important one was carried out by Pope and collaborators as a part of the Study II for Cancer Prevention. Data on factors relating to risk and air pollution were collected for a total of 500,000 adults in 151 metropolitan areas in the United States since 1982. In March 2002, the results were published of the follow-up of this cohort up to the year 1998 (Pope *et al* 2002). The fine particles (PM2.5) and sulphur oxides showed an association with mortality for all causes, for circulatory system causes and for lung cancer. Each increase by 10 $\mu g/m^3$ in atmospheric levels of fine particles was associated with an increase by approximately 4%, 6%, and 8% in the risk of death by all the causes, circulatory system causes and by lung cancer, respectively.

16.1.2.4. Effects of summer smog. Impacts of ozone upon health.

“Summer smog” type pollution refers mainly to photochemical pollution resulting from the reactions by hydrocarbons and nitrogen oxides, stimulated by intense solar light. **Ozone** is generally considered to be the most toxic component of this mixture. Ozone is formed by the action of the ultraviolet radiation of the sun upon NO_2. In the presence of volatile organic compounds, CO and methane, the formation of high concentrations of ozone is favoured.

Recent studies have described a large number of adverse effects caused by ozone. the most important being that related with respiratory diseases as a reduction in the pulmonary function (Galizia and Kinney 1999; Gauderman *et al*. 2002), exacerbation of asthma (Gauderman *et al* 2002) (McConell *et al*. 1999), increased risk of visits to the emergency ward (Tenias *et al*. 2002) and increases in hospital admissions (Anderson *et al*. 1997; Sunyer *et al*. 1997), and, probably, increased risk of death. (Burnett *et al*. 2001) (Goldberg *et al*. 2001). There is also evidence that people, especially the young, with airway hyperreactivtiy, such as asthmatics, are more sensitive to the effects of ozone.

16.1.2.5. Aeroallergens and respiratory health

Many studies have associated a high concentration of pollen and spores with epidemics of asthma and other allergic disorders, such as rhinitis or hay fever. In a recent study in Madrid (Tobías *et al* 2003) a significant association was established between increases in poceae and plantago pollen from the 95th to the 99th percentiles and an increase in visits to the Emergency Units of hospitals due to asthma, by 17% and 16% respectively. An association with urticaceae pollen, was also found, with an 8.5% increase in the number of visits to emergency units due to asthma. The role played by aeroallergens, however, in initiating or exacerbating asthma has not been clearly defined, and more research is therefore needed in order to establish the possible effects of climate change.

16.1.3. Infectious diseases

The emergence or re-emergence of most infections diseases is conditioned by evolutionary and environmental changes that can affect a large variety of intrinsic and extrinsic factors. Among the former is everything concerning the interaction between a pathogen and its vector, its intermediate host and its reservoir (infection, virulence, immunity and transmissibility). Among the latter are all the factors modulating the relationships between pathogen, vector and host/s, and environmental conditions (climate, meteorological conditions, habitats, ecosystems, housing development, pollution).

Climate changes can specifically affect temporal and spatial distribution, as well as the seasonal and interannual dynamics of pathogens, vectors, hosts and reservoirs. The phenomenon of the "Niño/southern oscillation" (ENSO) is the best known example of natural climatic variability and is associated with an increase in the epidemiological risk of certain diseases transmitted by mosquitoes, above all, malaria. It has been observed that, during the *El Niño* phenomenon, there was a 30% increase in malaria cases in Venezuela and Colombia, cases were multiplied by four in Sri Lanka and appeared in Northern Pakistan. More cases of dengue have been recorded in the Pacific Isles, Southeast Asia and South America. There has also been an increase in cases of Murray valley encephalitis and disease caused by Ross river virus in Australia, and cases of Rift valley fever in East Africa (Kovats 2000; Kovats *et al* 2003). The incidence of visceral leishmaniasis increased by 39% and 33% in 1989 and 1995 respectively, following the climatic oscillations of El Niño in the state of Bahía (Brasil) (Franke *et al* 2002).

A very illustrative example is what happened in California in 1984: coinciding with excessive rainfall and a warmer winter during the months of January and February, followed by drought and high temperatures (which reached 30ºC), in July there was an outbreak of San Louis encephalitis associated with a proliferation of mosquitoes of the genus *Culex* (Monath *et al* 1987) (this type of climate, with warm, rainy winters followed by hot, dry summers, are similar to the predictions of change for Spain). More recently, West Nile encephalitis was introduced into New York by migratory birds and later spread throughout the United States. This shows us how unexpected diseases can emerge.

16.2. SENSITIVITY TO THE PRESENT CLIMATE

16.2.1. Extreme temperatures

16.2.1.1. Different thresholds per province capitals for heat waves and cold spells

Having demonstrated the association between maximum daily temperature and the aforementioned excess mortality due to cold and heat, the different temperature thresholds above which excess mortality occurs can be calculated using the temperature records from the weather stations in each area. Figure 16.2 show the thresholds according to different province capitals that allow heat waves to be defined. In the case of heat, these values range from 26.2 ºC in A Coruña to 41,2 ºC maximum daily temperature for Cordoba, and for cold, from 2.7 ºC daily maximum in Ávila to 15ºC in Alicante.

These different physiological adaptation thresholds indicate that minimum mortality occurs at higher temperatures in the more temperate regions (Curriero *et al* 2002) heat having a greater impact at cold latitudes and a lesser impact at the more temperate ones (Davids *et al* 2002).

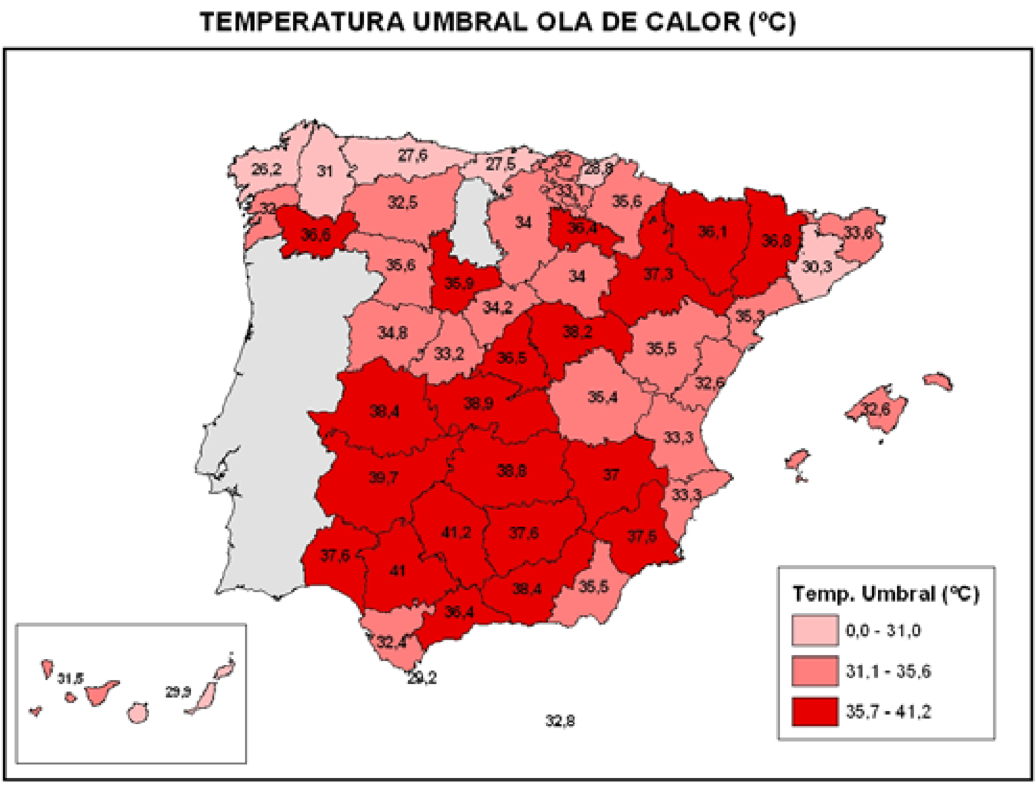


Fig 16.2. *Threshold temperatures for defining a heat wave (ºC) according to the 95th percentile for the series of maximum daily temperatures in the June-September period.*

16.2.1.2. Definition of an index for characterising the intensity of heat waves and cold spells

Considering the criteria that it is necessary to calculate not only excesses (defects) of maximum daily temperature in relation to the aforementioned thresholds, and even the duration of the thermal extreme, the following index can be defined to characterise the intensity of heat waves (IOC) and cold spells (IOF):

Heat:

$$IOC = \sum \left(T_{max} - T_{umbral}\right) \; si \;\; T_{max} > T_{umbral}$$

$$IOC = 0 \qquad\qquad\qquad si \;\; T_{max} < T_{umbral}$$

Cold:

$$IOF = \sum \left(T_{umbral} - T_{max}\right) \; si \;\; T_{max} < T_{umbral}$$

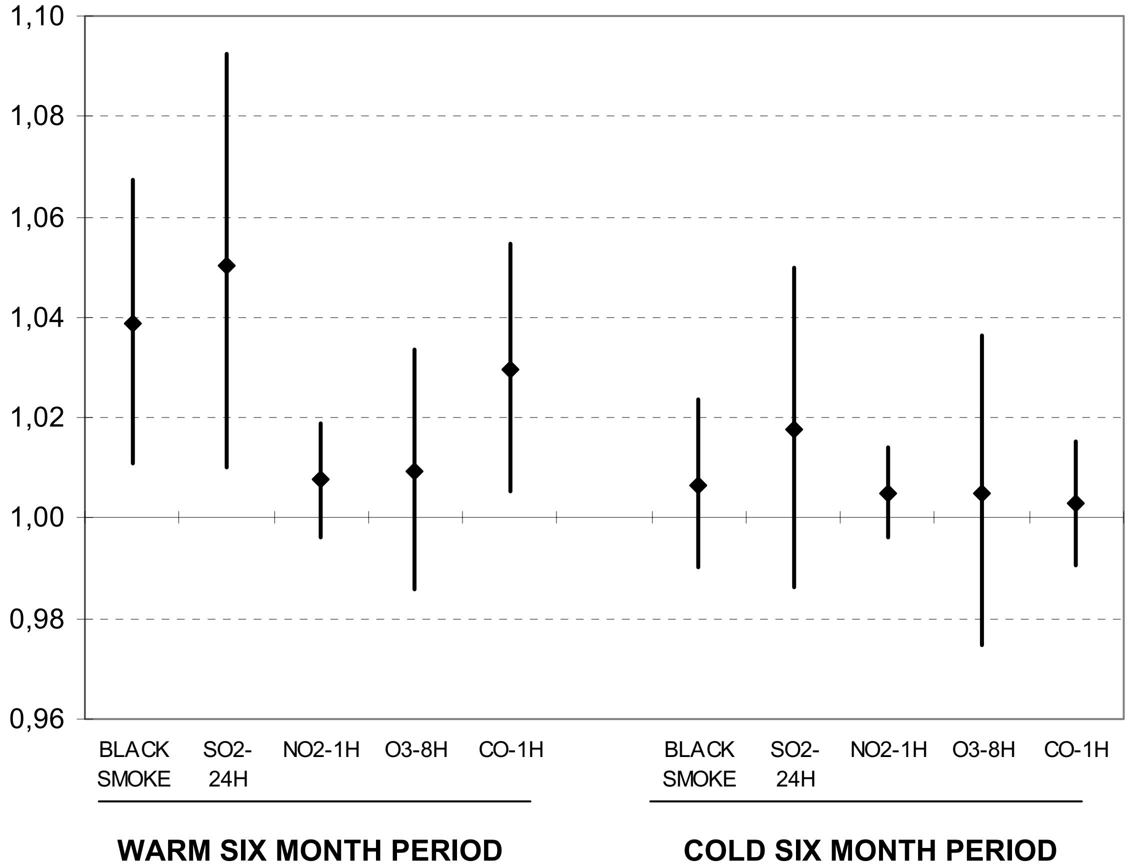
$$IOF = 0 \qquad\qquad\qquad si \;\; T_{max} > T_{umbral}$$

In the previous expressions, the sumatorio is extended to the time period to be characterised with the use of the index.

16.2.2. Air pollution

16.2.2.1. Sensitivity to air pollution

We need to recognise that there is still great uncertainty regarding sensitivity (that is to say, the change rate in the outcome variability by unit of change in the exposure variable) of the association between air pollutants. It is well known, however, that the effects of exposure to air pollution are many and with different degrees of severity, the respiratory and cardiocirculatory systems being the most affected. These effects maintain a gradation of both the seriousness of the consequences and the risk population affected (Figure 16.3). Particles constituted the most extensively studied group (Table 16.2).



24, 8H 1H: average concentration of the correspondant air pollution on 24, 8, and hours, respectively

Fig. 16.3. *Association between air pollution and daily emergency hospital admissions resulting from cardiovascular diseases. Analysis per six-month periods. Valencia 1994-1996. The results are expressed as the relative risk (and the confidence interval of this up to 95%) of an increase by 10 µg/m^3 (1 mg/m^3 for CO) in the daily levels of the corresponding pollutant. Source: Ballester et al 2001*

Table 16.2. *Study of the effects described for exposure to particles. Percentage change in health indicator due to increased particles concentration.*

Effects	Acute exposure Increase: 10μg/m³ of PM_{10}	Chronic exposure Increase: 5μg/m³ of $PM_{2.5}$
Increased Mortality*	*(Ecological studies, time series)	*(Cohort studies)
Causes		
- All except external ones	0.2[a] - 0.6[b,c] - 1.0	2[i] - 3
- Cardiovascular	0.7[c,d] to 1.4	3[i] - 6
- Respiratory	1.3[c] to 3.4	
- Lung cancer		4[i]
Increase in hospital admissions		
- All the respiratory ones	0.8 to 2.4[e]	
- EPOC	1.0[f] to 2.5	
- Asthma	1.1[f] to 1.9	
- Cardiovascular	0.5[g] to 1.2[h]	
Illness: bronchitis		7
Reduced pulmonary function (VEF_1)		
- Children	0.15	1
- Adults	0.08	1.5

Adapted from Pope and Dockery (1999), with the inclusion of the results of recent multicentre studies: a: Dominici et al (2002b); b: Katsouyanni et al. (2001); c: Stieb et al. (2002); d: Samet et al. (2000a); e: Biggeri et al. (2001), f: Atkinson et al (2001b), g: Le Tertre et al. (2002), h: Samet et al. (2000c), i: Pope et al (2002).

In Spain, the results of the joint analysis with available data for 13 cities in the EMECAS project indicate that an increase by 10 μg/m³ in the levels of black smoke is associated with an 0.8% increase in the number of daily deaths. A significant association has also been found between mortality and all the other pollutants. For the groups of specific causes, the magnitude of the association was greater, particularly for respiratory illnesses (Ballester *et al* 2003). With data for 3 cities, ozone only showed an association with cardiovascular mortality during the hot six-month period (Sáez *et al* 2002).

Finally, and from the public health point of view, it should be pointed out that although the impact on health is of little magnitude, a high proportion of the impact can be attributed to pollution, given that the whole population is exposed. Furthermore, together with the proved effects above, it is important to consider the potential impact of exposure to air pollution during pregnancy and first childhood, as showed in some studies. Results from a recent review on the subject (Lacasaña *et al* 2005) show an association between exposure to air pollution and low birth weight and intrauterine growth retardation, as well as an impact of early exposure on infant health including an increase in mortality. Coinciding with the Inter-ministerial Summit in Budapest, June 2004, a report has been presented evaluating the burden of some ambient exposures in Europe among infant health. Results from such report show that among European infants between 0-4 children 1.8% to 6.4% of all deaths for total causes could be due to outdoor air pollution, and 4.6% to exposure to air pollution indoors. Persistence of bad air quality situations, or its possible worsening, may represent a risk for the health of children and future generations.

16.2.2.2. Factors modifying the effects of climate change and of air pollution.

On interpreting studies that examine the relationship between air pollution and health, we must consider several factors which could confuse the study of the association with health indicators. These factors are the following: a) those determined by geophysical cycles, b) meteorological ones, and c) the sociocultural ones, such as, for instance, the life pattern conditioned to the week organisation. We would also have to consider illnesses with a seasonal behaviour, like influenza.

Furthermore, a greater influence of certain air pollutants during the hotter months of the year has been observed. Thus, a greater effect of SO_2 has been described (Ballester *et al*. 1996, Michelozzi *et al* 1998) ; or of particles (Biggeri *et al*. 2001; Ballester *et al*. 2001) on cardiovascular mortality and morbidity (Figure 16.3). In the APHEA 2 study (Katsouyanni 2001) it was found that, both mean annual temperature and the location of the city in Europe (North, South, East), that is, climate-related components, helped to modify the effects of pollution on mortality. The effect of particles on mortality was greater in the cities with warmer climates.

Different hypotheses have attempted to account for these findings. On one hand, measurement of air pollution during the hot months could be a more accurate indicator of total exposure of the population, because people spend more time in the street and windows are kept open for longer (Katsouyanni 1995). Besides, during the hotter months, individual susceptibility to pollution might increase, due to processes such as the increased effect of particles upon the plasmatic viscosity regulation system (Pekkanen *et al*. 2000). Another reason is that there could be a selective emigration of the population from the cities during summer, with more elderly people remaining in the cities (Biggeri *et al* 2001).

Different studies have described a greater effect of ozone during the days with higher temperatures (Sartor *et al* 1995) or in the hotter months (Sunyer *et al* 1996, Touloumi *et al* 1997). The EMECAS study described the influence of ozone on the number of admissions of people with diseases of the circulatory system, which is significant in the hotter months, but not during the rest of the year (EMECAS project, submitted).

16.2.3. Infectious diseases

Changes in temperature, precipitation or humidity affect the biology and ecology of vectors, and those of intermediary hosts or of natural reservoirs (Githeko *et al* 2000). Furthermore, forms of human settlement could also have an influence: dengue is basically an urban disease and would have a greater effect in very urbanised communities with a deficient waste waters and solid wastes elimination system.

Classically, one of the mathematical expressions most used, initially by malariologists, to quantify the vectorial capacity (C) of an arthropod has been defined as: Vectorial capacity: C= $\frac{ma^2p^n}{-\log_e p}$, where **m** is the density of the vector arthropod per human, **a** the daily rate of bites on a vertebrate host multiplied by the probability that that vertebrate is a human, **p** the daily survival rate of a vector and **n** the latent period of the pathogen in the vector arthropod (extrinsic incubation).

16.2.3.1. Effects of temperature

Temperature is a critical factor upon which both vectorial density and vectorial capacity depend: it increases or decreases the survival of the vector, conditions the growth rate of the vector population, changes the susceptibility of the vectors to pathogens, modifies the extrinsic incubation period of the pathogen in the vector and changes the activity and pattern of seasonal transmission.

On increasing water temperature, mosquito larvae need less time to mature and, consequently, the number of descendants increases during the transmission season. The egg-adult metamorphosis period is shortened, the size of the larvae is reduced, and adults are generated in a shorter time period, but these are smaller and females therefore have to consume blood more often in order to lay eggs, which leads to an increase in the inoculation rate. The extrinsic incubation period (the time taken by the arthropod from when it is infected until it becomes an infective agent) has a direct relationship with temperature: the higher the temperature the shorter this period is.

It is very likely that the effect of climate change on diseases transmitted by arthropods will be observed on varying the transmissibility temperature limits: 14-18ºC as the lower limit and 35-40ºC as the higher one. A minimum increase in the lower limit could lead to the transmission of diseases, whereas an increase in the upper limit could suppress this (above 34ºC the life of the mosquito is significantly shortened). At around 30-32ºC, however, vectorial capacity can be substantially modified, as small temperature increases shorten the extrinsic incubation period, and transmissibility is increased.

Climate decisively affects the phenology of many arthropods which even fall into a lethargic state (diapause) in the unfavourable season, and this behaviour is very generalised in species in the Palaeartic region. The seasonal activity period of many species can be lengthened according to the prolongation of favourable climatic conditions.

16.2.3.2. Effects of rainfall

An increase in rainfall could increase the number and quality of vector breeding places and vegetation density, which would provide ecosystems in which to alight and which would provide better shelter and food for intermediate host rodents. Flooding, however, would eliminate the habitat of vectors and vertebrates, but would force vertebrates into closer contact with humans. Droughts in humid sites would slow river flows, creating still waters which would also increase the breeding places and would cause greater dehydration of the vector, which would force it to feed more frequently, in other words, to increase the number of stings/bites.

16.2.3.3. Other factors

Housing development increases the density of susceptible human hosts, with worse hygiene conditions in poorer countries, which increases the transmissibility rate for the same number of vectors. Furthermore, urban development in the vicinity of rural or forested areas can lead to an increase in contact between man, vectors and selvatic reservoirs.

Deforestation allows humans to enter the forest, which becomes agricultural land, which increases the number of possible vector breeding places and contact between man and vectors and reservoirs.

Irrigation and water supply schemes increase the aquatic area and prevent flooding and drought, which also increases vector breeding places.

Agricultural intensification increases erosion and water areas and reduces biodiversity, thus reducing vector predators and increasing vector breeding places.

Chemical pollution by fertilisers, pesticides, herbicides and industrial waste may negatively affect the human immune system, making man more susceptible to infections.

Increased international trading could lead to the import of vectors from remote parts of the world.

Population movement resulting from tourism, work or immigration can cause the import of diseases from endemic areas.

16.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

16.3.1. Extreme temperatures

Thermal extremes associated with climate changes will clearly have a direct effect on excess mortality. In the case of heat waves, this impact will be seen in an increase in the excess mortality associated with these extreme events Díaz *et al* 2002a, Smoyer 1998). Predictions indicate and increase in the intensity and frequency of heat waves, especially during the first months of summer (Hulme *et al* 2002). An example of this is the heat wave in France, from August 1st – 20th 2003, which caused excess mortality in relation to the same period in previous years of 14,800 people. In Italy, an increase by 4,175 deaths was estimated for the over 65 age group, from July 15th to August 15th. In Portugal, from July 31st and August 12th, there was an excess mortality of 1,316 people in relation to the previous year. In Great Britain, there was an increase of 2,045 people from August 4th to August 13th (Pirard 2003). In Spain, according to unofficial data, there was an excess mortality of over 6,000 people, compared with the same period in the previous year (WHO 2004, Martínez *et al* 2004)

16.3.1.1. Models for predicting temperature-related mortality

Regardless of the data for this last summer, studies based on analyses of time series of mortality and the relationship between these and temperature in the case of different cities, enabled us to quantify the impact of thermal extremes according to each degree by which maximum daily temperature exceeded the threshold of each one of them. Thus, studies have been applied to the case of mortality associated with heat waves for the cities of Madrid (Díaz *et al* 2002a), Seville (Díaz *et al* 2002b) and Lisbon (García-Herrera *et al* 2004). By way of an example, table 16.3 shows the mortality increase in persons over 65 years of age associated with each degree by which maximum temperature exceeds the 36.3ºC threshold temperature for Madrid.

Table 16.3. *Percentage of increased mortality due to different causes,sex and ge groups in Madrid City by each degree by which maximum daily temperature exceeds resulting 36.5 ºC.*

Causes of mortality	Men 65-74	Women 65-74	Men >75 years	Women >75 years
Organic (%)	14,7	16,2	12,6	28,4
Circulatory (%)	9,4	11,7	6,3	34,1
Respiratory (%)	17,2	23	26,1	17,6

According to these models, the heat wave in the summer of 2003, from July 1st to 31st, caused an excess mortality in Madrid of 141 deaths, approximately 95% CI: (81 200) of which 96 % involved persons of over 65 years of age. For Seville, the excess mortality in over-65s totalled 43 deaths, 95% confidence interval: (20 - 66).

The previous definition by the intensity index of the heat wave enabled us to identify the provinces in our country in which heat had the greatest influence on mortality in the year 2003. In general terms, it was in the places in which heat is more infrequent where the highest values of this index were reached in summer. The behaviour of the index calculating the intensity of the heat wave in relation to the mortality rate in the provinces of Spain with over 750,000 inhabitants is of a logarithmic nature (Díaz *et al* 2004b) which indicate that small increases in the index have a great effect on mortality, and that, partly due to the harvester effect, there is a threshold above which the effect becomes stabilised.

Although at global level, the different patterns of expected mortality based on future scenarios of climate change (McGeehin and Mirabelli 2001) refer to an increase in mortality related to heat waves and a decrease related to cold, it is also true that studies in Europe (Eurowinter Group 1997) indicate that cold has an influence on mortality, greater in those places with more temperate winters than in areas with harsher ones. On one hand, this is due to physiological adaptation to low temperatures, and, on the other, to the infrastructures of homes, which mean that conditions referring to the fight against cold, in places accustomed to cold spells, are better than in which cold is more infrequent (Eurowinter Group 1997). By way of an example, table 16.4 shows the effects of the days in which maximum daily temperature is below the aforementioned threshold on mortality in the over-65 age group in Madrid (Díaz *et al* 2004a)

Table 16.4. *Percentage of increase in mortality in the City of Madrid, according to age groups and specific causes by each degree by which maximum daily temperature does not reach 6 ºC.*

Causes of Mortality	Age from 65 to 74 years	Over 75
Organic (%)	5,1	2,7
Circulatory (%)	6,1	2,8
Respiratory (%)	9,1	9,6

16.3.1.2. Evolution models of mortality rate for the horizon of the years 2020 and 2050

A recent study applied to the city of Lisbon (Dessai 2003) evaluated, although with a high degree of uncertainty, the possible increase in the gross mortality rate for the years 2020 and 2050. Predictions by two regional climate models were used, as well as different hypotheses referring to the acclimatisation and evolution of the population. According to this study, the increase in mortality rate associated with heat was between 5.4 and 6 for every 100,000 inhabitants in the 1980-1998 period. Between 5.8 and 15.1 for the horizon of 2020 and from 7.3 to 35.6 for 2050.

16.3.2. Air pollution

16.3.2.1. Annual tendencies and seasonal variation of air pollutants.

The SESPAS 2000 report described the descending tendency of levels of SO_2 and of black smoke, particularly of the former, in the last 20 years (Fernández-Patier and Ballester 2000). These pollutants are the ones traditionally included in air pollution monitoring and control programmes.

In Spain, information is currently available for the evaluation of the present situation, with a certain perspective, and of the tendencies of other pollutants relevant to human health (Figure 16.4).

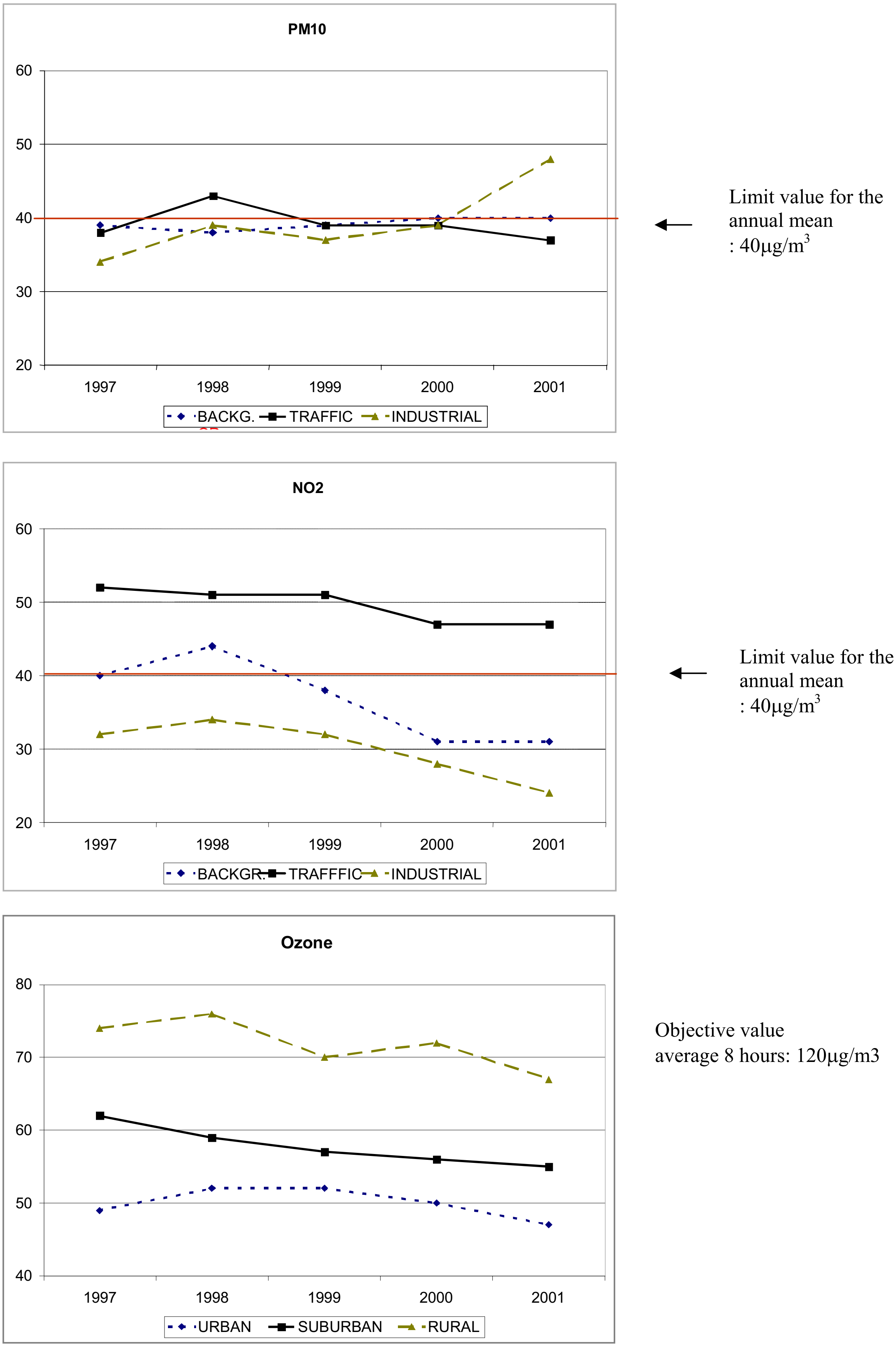


Fig. 16.4. *Average of the annual mean values of levels of PM10, NO2 and Ozone (in $\mu g/m^3$). Spain 1997-2001. Source: Air Quality Database, Ministry of the Environment 2003.*

Given that most of Spain's population lives in urban areas, the data corresponding to the PM10 and NO_2 are presented for the urban-type stations, with a distinction between those directly influenced by the traffic in a nearby street (traffic monitoring stations), and those mainly influenced by industrial factors (industrial monitoring stations) and, lastly, are not very much directly affected either by traffic or by industry (urban background monitoring stations). For these two pollutants, we can see how the values recorded oscillate around the limit value stipulated in European and Spanish regulations, which is 40 $\mu g/m^3$ as a mean annual value, set to be reached in the year 2005 or 2010, respectively (European Union Council 1999). In both cases, we must take into consideration that the values shown are the mean values of annual averages in each one of the 150 urban monitoring stations. Which means to say that in many of these cities, the annual values will be greater than the threshold value established by Spanish and European regulations.

In the case of the *PM10* the values obtained in the different types of stations present a stable tendency, with no big changes in these last 5 years. Furthermore, it can be seen that, in urban areas, particle pollution does not directly depend on the proximity of the emission sources, but rather, is distributed in quite a homogeneous manner throughout developed areas. In terms of public health, this fact is significant, because it suggests that the percentage of people exposed to average concentrations of over 40 $\mu g/m^3$ of PM10 could be high. We must consider, however, that the composition of the particles can vary substantially from one place to another, and that the toxicity of the particles appears to be related, among other things, to their composition and size. In this sense, more information would be needed in relation to the values of fine particles (PM2.5) and to the composition of these, in order to better evaluate their origin and possible impact on health.

The *NO2* values indicate a different pattern. In this case, the highest values are clearly recorded in the traffic monitoring stations indicating that this pollutant could be a good pollution indicator, due to emissions from motor vehicles. Furthermore, in the urban background and industrial monitoring stations a certain decrease was observed, and this tendency is not clearly seen in the traffic monitoring stations.

For *ozone*, as this is a secondary pollutant which usually reaches the highest values in areas distant from the emission sources, the values measured in urban background monitoring stations are represented, located in urban areas, suburban and rural ones. In the sub-urban monitoring stations, which represent exposure by a high percentage of the population, mean annual concentrations reach 60 $\mu g/m^3$. Given the high annual seasonality, with higher values in the hotter months, and the daily ozone pattern, with sharp peaks during the hours of solar radiation, it is certain that, in many days of the year the threshold values of 120 $\mu g/m^3$ will be surpassed for values of the daily maximum of 8 hours. Stability is generally observed, or a certain tendency of mean concentrations to decrease; the period considered, however, is very short to be able to identify a consistent pattern.

16.3.2.2. Seasonality and influence of meteorological conditions in relation to the emission, transport and formation of air pollutants.

Seasonality can vary from one place to another, basically depending on emissions and meteorological phenomena. There is, however, a homogeneous pattern in most Spanish cities, and primary pollutants from the combustion of fossil fuels present a pattern with higher values in winter (due to greater emission and conditions of meteorological stability) and lower values in the summer months. On the other hand, ozone presents the opposite pattern, with higher values during the months with higher temperatures, due to the interaction of ultraviolet rays with the precursory gasses (NO_2, VOC) from the exhausts of vehicles and from other sources. This pattern could be different for pollutants that are transported over long distances. In Spain, this is the case of pollution episodes caused by particles, occurring in the Canary Isles and part of the

Iberian Peninsula, as a result of dust transported from the Sahara desert (Viana *et al* 2002; Rodríguez *et al* 2001). This should be taken into account when evaluating particle levels in our country, because in certain circumstances, an important part of these involve dust from the Sahara.

Concentrations of air pollution depend on their production, and in a determinant way, on their dispersal. Climate change can affect either of the two aforementioned processes. On one hand, related to meteorology, the possible greater frequency of anticyclonic phenomena could reduce pollutant dispersal. Another meteorological phenomenon predicted as a consequence of climate change will be an increase in dry storms with dust transported from the Sahara and other places. On the other hand, and as will subsequently be described, temperature increase is very directly correlated to ozone concentrations. Lastly, and in an indirect way, a temperature increase could be associated with an increase in pollutant emissions resulting from greater energy consumption due to the use of air conditioning, cooling and refrigeration systems.

Although it would be necessary to establish the specific predictions for Spain (see other chapters of this report), given the fact that *ozone* is a secondary pollutant, we could expect climate change to be associated with increases in ozone levels.

It is difficult to predict how climate change will affect the levels of other pollutants. Pollutants more related to heating systems, such as SO_2, will possibly be less used, thus reducing emission thereof. For other pollutants, however, such as fine particles, NO_2 or CO, which are very much related to emissions from motor vehicles, it is quite difficult to predict tendencies. These will be determined to a great extent by the tendencies of fossil fuel combustion. At a local scale, there may be episodic situations of air pollution associated with meteorological phenomena involving high pressures and a lack of prolonged rainfall. Lastly, global warming could lead to an increase in the number and intensity of forest fires. The smoke produced by these fires has been related to increased respiratory disorders among the population affected.

16.3.2.3. Influence of meteorological conditions in the production and release of pollen and spores

In spite of the fact that pollen and spore concentrations depend to a great extent on the existing crop and wild species, variations in these concentrations depend very much on meteorological factors (McMichael AJ and Githeko AK 2001). Climate change could advance or lengthen the pollen period for certain species with an allergenic capacity. Besides, increased CO_2 levels could affect pollen production.

16.3.3. Infectious diseases

16.3.3.1. Malaria

16.3.3.1.1. Transmissibility

The natural transmission of this disease occurs through the bite of mosquitoes of the genus *Anopheles*. Of over 3,000 species of mosquitoes distributed throughout the world (particularly in warm and tropical areas), 400 are anophelines, 70 transmit malaria and only around 40 are of medical importance: *Anopheles gambiae* and *Anopheles funestus* are the main vectors in tropical Africa. These insects undergo a complete metamorphosis, passing through four clearly differentiated phases: egg, larva, pupa and adult, the first three aquatic and the last one aerial. The duration of this metamorphosis varies according to environmental temperature, from seven days at 31ºC to twenty days at 20 ºC. The males only live for a few days, and, as they do not feed on blood, they play no role in the transmission of the disease, except fertilising the females, which is done immediately after these hatch. The females are fertilised only once, and the keep the sperm in an internal reservoir for subsequent fertilisation. The first laying of eggs usually occurs on the 4th or 5th day of life of the mosquito and successive layings every 2-3 days, coinciding with the bite, as the mosquito seeks blood (which is known in entomology as “gonotrophic concordance”. Once the mosquito is infected, it remains an infective agent all its life, and requires around ten days for the *Plasmodium falciparum* (extrinsic incubation period) to develop therein, and the female must therefore survive for at least four or five gonotrophic cycles in order to transmit malaria (that is, at least for 10-12 days). The longevity of the female mosquito in favourable conditions is around four weeks in Africa, although some warm climate species can survive for up to six months, on falling into winter lethargy. Most bite at night, especially from 20 to 03 hours and the most efficient ones with regard to transmission are those that have anthropophilic habits (only biting humans), endophagic and endophilic ones (which do so inside the house). There is a clear decrease in bites if relative humidity is below 52%. The optimum temperature for the development of the mosquito is 20-27ºC and 22-30ºC for the parasite (22ºC for *Plasmodium malariae* 25ºC for *Plasmodium vivax* and 30ºC for *P.falciparum*). There is no transmission at altitudes of over 3,000 metres or at constant temperatures of below 15 ºC, as the schizogony is paralysed (for *P.vivax* this is below 16ºC and for *P.falciparum* below 19ºC). There is no transmission, either, if the temperature remains constant at over 38ºC.

“Sporozoite index” is the term given to the proportion of female anophelines infected in a determined area (that is, the percentage that has sporozoites in their salivary glands), which in tropical Africa is 2-5%, whereas in other malarial areas it is 0.2-2%.

In malariology, the terms indigenous or autochthonous malaria are used when it is contracted through the bite of a mosquito infected in a country in which malaria exists. It is called introduced malaria when it is contracted in a country where malaria does not exists, through local mosquitoes that have been infected by someone infected by imported mosquitoes. Induced malaria is that transmitted by blood or organs. It is called airport malaria (or more generally, odyssean malaria) when it is caught in a country where malaria does not exist, by infected mosquitoes transported from endemic areas in baggage or aeroplanes, boats, busses, containers..., and 75 cases of this have been described for Europe in the 1997-2000 period (Mouchet 2000)

16.3.3.1.2. Malaria in Europe

In the past, malaria was transmitted throughout Europe, reaching as far north as England, Scotland, Denmark, southern Norway, southern Sweden, Finland and the Baltic provinces of Russia. At these latitudes, winters can reach -20ºC, and transmission depended upon how warm the winters were (limited to the 15ºC isotherm in July). But half-way through the XIX century, malaria disappeared from northern Europe and declined in the Centre (for example: the last outbreaks in Paris occurred in 1865, during the construction of the big boulevards) , and disappeared after the I world war. In southern Europe, it remained very prevalent (due to poverty and underdevelopment) until after the II world war, when an effective programme of vectorial control was introduced (with the revolutionary appearance of DDT), and by 1961 it had been eradicated from most countries.

In the 90s, there were outbreaks in the new states in the south of the ex - Soviet Union, with local transmission through import by troops returning from Afghanistan. At present, it is only transmitted (exclusively *P.vivax*) seasonally in very specific points of Armenia, Azerbayan, the Russian Federation, Turkmenistan, Uzbekistan and the Asian part of Turkey.

Occasionally, an autochthonous case is described in Europe, with no secondary transmission, but worrying in any case, such as in Italy, where cases of local transmission of *P.vivax* have been recorded and where anopheline density has shown spectacular growth in areas like Tuscany and Calabria (Baldari *et al* 1998).

16.3.3.1.3. Malaria in Spain

Benign tertian fevers by *P. vivax*, and to a lesser degree the malignant tertian ones by *P. falciparum* and quartan ones by *P. malariae*, were endemic in Spain until relatively recently. The last case of autochthonous malaria was recorded in May 1961 and in 1964 the official certificate of eradication was issued. Since then, all cases reported have been imported, with the exception of induced ones or those caused by exchange of syringes by drug addicts through parenteral administration or of airport malarias, although recently, a possible autochthonous case by *P. ovale* was described, in Alcalá de Henares (Madrid), but it may be a case of airport malaria caused by the proximity of the aerodrome at Torrejón de Ardoz (Cuadros *et al* 2002).

The only potential vector still present in Spain is *Anopheles atroparvus* the populations of which is still widely distributed throughout large areas. Fortunately, it is refractory to tropical strains of *P. falciparum*, which limits autochthonous transmission through cases contracted in sub-Saharan Africa (Ramsdale and Coluzzi 1975). *Anopheles labranchiae*, the other vector involved in the transmission of malaria, disappeared from the Southeast of the Peninsula in the 70s. Every year, over 400 cases of malaria are declared in our country, but to date this has not determined the re-introduction of the disease, in spite of the increase in potentially infected tourists and immigrants.

The malariogenic potential in Spain is very low, and the re-establishment of the disease is highly unlikely, unless social and economic conditions were to deteriorate drastically and rapidly. Any possible local transmission would be limited to a very small number of people and would be of a sporadic nature. Furthermore, the parasites that could most likely cause these cases would be the benign forms of malaria caused by *P. vivax / P. ovale*, as they can develop at lower temperatures and in peninsular vectors.

The most cautious predictions for the year 2050 do not indicate the Iberian Peninsula as a scenario for malarial transmission, but rather along the coast of Morocco (Rodgers and Randolph 2000). There is a possibility, however, that African vectors susceptible to tropical strains of *Plasmodium* could invade the South of the Iberian Peninsula (López-Vélez and García 1998), although exposure would be reduced with the increased use of air conditioning (Reiter 2001).

16.3.3.2. Viruses transmitted by mosquitoes

Over 520 of these viruses have been identified, of which around one hundred are pathogens for man. The most harmful ones are those that can cause haemorrhagic fevers or encephalitis. The term arbovirus (arthropod-borne-virus) is used for those transmitted by the bite of arthropods, fundamentally by mosquitoes of the genera *Aedes* and *Culex*.

Aedes aegypti, a vector of yellow fever and dengue in the tropics, appears to have disappeared from Europe and at present, it is not found above the de 35º northern latitude. To the contrary, this continent has been entered by *Aedes albopictus,* a vector of dengue (the 4 serotypes) and of yellow fever, originating in Southeast Asia and the sub-continent of India (it is also a potential vector of other viruses such as Japanese encephalitis, western equine encephalitis, Ross river fever, La Crosse, Chikungunya, Rift valley fever and West Nile fever. It is also a good vector of *Dirofilaria immitis* and *Dirofilaria repens.* In theory, it survives up to such northern latitudes as 42ºN (almost the lower two thirds of the Iberian Peninsula), but as it is capable of entering diapause when climatic conditions are unfavourable, the real limiting factor would be the -5ºC isotherm in January, which would make establishment possible as far north as southern Sweden. Furthermore, in both urban and rural environments, it feeds on the blood of mammals, birds and humans, which makes it an excellent connecting vector between wild and urban cycles and between animals and humans. Once infected by dengue, it can spread this virus vertically and through transovarial transmission to its larvae. In the 80s, it was introduced into the Americas in a cargo of used tyres from Japan. In Europe it was first detected in 1979 in Albania, apparently coming from China, it reached Italy from the USA in 1990 and after 2000 it appeared in France, Belgium, Montenegro, Switzerland and Hungary, and what was feared has happened, as it has just been detected in Spain (Aranda*, pers. comm.*).

16.3.3.2.1. Dengue

16.3.3.2.1.1. Transmissibility

The dengue virus is a flavivirus, of which there are 4 serotypes, with a wide range of clinical symptoms, from asymptomatic infections to potentially lethal haemorrhagic pattern. Every year, there are 250,000-500,000 cases of serious forms (haemorrhagic dengue- and shock dengue), producing a death rate of 1-5% which can reach 40% if untreated. There is no effective vaccine against this disease.

It is an urban environment disease, with explosive epidemics reaching up to 70-80% of the population. Transmission occurs through the bite of the mosquito *A. aegypti* and to a lesser extent by *A. albopictus* and takes place between the parallels 30ºN and 20ºS. Since the 50s, an evident re-emergence has been observed in Southeast Asia, and since the 70s, on the American continent.

The extrinsic incubation period in the mosquito is 12 days at 30ºC, but if the temperature rises to 32-35ºC this period is reduced to only 7 days. At 30ºC, a human being with dengue must infect 6 mosquitoes for a secondary case to occur, whereas at 32-35ºC only 2 mosquitoes need to be infected for this to happen, that is, the vectorial capacity of the mosquito is multiplied by 3 (Rogers and Packer 1993).

16.3.3.2.1.2. Dengue in Europe

Dengue existed in Europe in the past. The first serologically documented epidemic (in a retrospective manner) was in Greece during the years 1927-1928, with over 1 million people infected, of which over 1,000 died of haemorrhagic dengue. After the second world war, the transmission of dengue ceased in Europe, probably as a consequence of the malaria eradication campaigns with DDT.

At present, there is no documented transmission of dengue in Europe, but the worst is feared, as *A. albopictus* is well-established in Albania and Italy and, as has been previously mentioned, its presence has been detected in Belgium, France, Montenegro, Switzerland, Hungary and Spain.

16.3.3.2.1.3. Dengue in Spain

Epidemics have been described since the XVII century that might very well have been dengue, including the outbreak in Cadiz and Seville from 1784 to 1788 (Rigau 1998). In mid-June 1801 the Queen of Spain suffered symptoms of what appeared to be haemorrhagic dengue, and during the XIX century, there were epidemics in the Canary Isles, Cadiz and other parts of the Mediterranean associated with cases imported by sea.

There are no documented cases of local transmission of dengue, but there seems to be an evident risk, as Spain has the appropriate conditions for transmission: high summer temperatures and large urban nuclei, where windows are kept open and the use of air conditioning is infrequent, and there is much activity in streets and parks (ideal for contact with the vector). Although at present *A. aegypti*, one of the most important vectors of this disease, appears to have disappeared from Spain decades ago, the presence of *A. albopictus*, the second most important vector, has just been confirmed in Catalonia (Sant Cugat del Vallès) (Aranda, *pers. comm.*). The ideal climatic conditions for the development of this mosquito are: over 500 mm^3 annual rainfall, over 60 days rainfall per year, mean temperature of the cold month above 0ºC, mean temperature of the warm month over 20ºC and mean annual temperature over 11ºC. The areas believed to be most suitable for the development of this vector in Spain are Galicia, the whole Cantabrian coast, the sub-Pyrenees, Catalonia, the Ebro delta, the Tajo basin, the Guadiana basin and the mouth of the river Guadalquivir (Eritja, pers. comm.).

16.3.3.2.2. Viral encephalitis. West Nile virus

16.3.3.2.2.1. Transmissibility

Representing a wide range of viral diseases (Saint Louis encephalitis, western equine encephalitis, Venezuelan equine encephalitis, West Nile…) that are transmitted by the bites of different species of mosquito, especially of the genus *Culex* (*C. quinquefasciatus*, *C. pipiens*…) and of ticks, birds constituting the main reservoir of the disease. Transmission is impossible at isotherms of below de 20ºC in summer. These cause a pattern of meningitis or meningoencephalitis that can cause permanent neurological damage. Although it mainly circulates among birds, many species of mammals can also be infected, such as amphibians and reptiles.

Outbreaks of Saint Louis encephalitis associated with climate changes were detected in California in 1984 and of Venezuelan equine encephalitis in Venezuela and Colombia during 1995. West Nile virus is endemic in Africa, and very noteworthy was the outbreak in New York in 1999, which subsequently spread to 44 states and to 6 provinces of Canada in just five years, transmitted by mosquitoes of the genus *Culex* from infected migratory birds.

16.3.3.2.2.2. Viral encephalitis in Europe

Epidemic outbreaks of West Nile were detected in the eastern Mediterranean, the Camargue in the 60s and in the surroundings if Bucharest (Rumania) in 1996. During the months of August-September 2003, a small outbreak was detected in the Var region in France (where there had been an outbreak of equine encephalomyelitis in 2000) which affected two humans (who, in fact, had spent their holidays on the East coast of Spain) and three horses. During this outbreak, in Spain around 80 samples of cerebrospinal fluid from patients with meningitis, and over 900 pooles of mosquitoes were studied, none of which were found to be positive. Other outbreaks have also been described in Italy, the Czech Republic, southern Russia and Georgia. In summer 2004, there was another small outbreak in the Algarve (Portugal), which seems to have affected two Irish tourists, although this outbreak is still to be confirmed.

16.3.3.2.2.3. Viral encephalitis in Spain

The Mediterranean basin and the South of the Iberian Peninsula in particular, which receive migratory birds from Africa, constitute high-risk areas for transmission. Seroprevalence studies carried out in Spain from 1960 to 1980 showed the presence of antibodies in the blood of inhabitants of Valencia, Galicia, Coto de Doñana wetlands and the Ebro delta, which means that the virus circulated throughout our country at that time (Lozano and Felipe 1998). The current impact this virus could have on the health of the Spanish is unknown, as it is not routinely researched in cases of viral meningitis. The association with climate change has not been established, but a temperature increase can be expected to cause an increase in vectors, and therefore, greater risk of transmission, which would lead to outbreaks of viral meningitis and encephalitis in populations in risk areas in Spain.

16.3.3.2.3. Yellow fever

16.3.3.2.3.1. Transmissibility

This disease in included within the haemorrhagic viral fevers and has a death rate of >40%. Fortunately, there is an effective vaccine for prevention. It is endemic on the continent of Africa and in the Amazon, and transmitted by the bite of the mosquito *A. aegypti*.

16.3.3.2.3.2. Yellow fever in Europe and in Spain

Spain, with its overseas colonies, was particularly vulnerable to this disease, and epidemic outbreaks associated with cases imported by sea were recorded: in 1856 there were over 50,000 deaths in Barcelona, Cadiz, Cartagena and Jerez (that same year 18,000 people died in Lisbon and there were many other cases in port cities in northern Italy and southern France) (Eager 1902). *Aedes aegypti* disappeared from the Mediterranean after the II world war, very likely as an indirect consequence of the programmes for the eradication of malaria, and since then, no risk of this disease has existed.

16.3.3.2.4. Leishmaniasis

Leishmaniasis re-emerged in Europe in the 60s, once the control programmes for the eradication of malaria had ended. A parasitic disease caused by *Leishmania infantum* in Spain, it is endemic in our country and from dogs to humans by diptera of the genus *Phlebotomus* (*P. perniciosus* and *P. ariasi*). It causes cutaneous leishmaniasis and severe visceral leishmaniasis.

Temperature increases could shorten parasitic maturation in the vector (increasing the risk of transmission), reduce the vectors' period of wintertime lethargy, with the consequent increase in the number of annual generations, and cause a change in geographic distribution, the more dangerous species being displaced towards the North of the Peninsula, at present free of the disease.

It is highly likely that the distribution of leishmaniasis on the European continent will spread northwards, as a consequence of global climate warming, from the present distribution limits of the disease. There is also a high risk that anthroponotic cutaneous leishmaniasis caused by *Leishmania tropica*, currently existing only in North Africa and the Middle East, will emerge at any moment in southern Europe.

16.3.3.3. Tick-transmitted diseases

16.3.3.3.1. Transmissibility

Ticks undergo a metamorphosis from the egg phase which includes three stages of development involving blood-sucking (larvae., nymphs and adults). It is the nymphs, however, that most contribute to the transmission of diseases to humans from animal reservoirs. The diseases are many and of varying seriousness: borreliosis (endemic relapsing fever, Lyme borreliosis), rickettsiosis (boutonneuse fever, spotted fevers), babesiosis, anaplasmosis, ehrlichiosis, tularemia and viral diseases (encephalitis caused by tick bite or Centro-European encephalitis, Crimean-Congo haemorrhagic fever, Kyasanur forest disease...).

In Spain, the most serious diseases are boutonneuse fever and Lyme borreliosis and the most widespread ticks are *Rhipicephalus sanguineus*, the "common dog tick" involved in the transmission of Mediterranean spotted fever and *Ixodes ricinus,* involved in the transmission of Lyme borreliosis.

The average life of a tick can exceed 3 years, depending on climatic conditions. The three stages of the vector can be infected, and what is most dangerous, it can transmit the infection to its young through transovarial transmission.

They can survive temperatures as low as -7ºC, recovering vital activity at 4-5ºC. They are very sensitive to minimum temperature changes, as can be seen in the fact that an isotherm of just 2ºC conditions transmission in southern and eastern Africa. Decreased humidity causes a notable reduction of viability of the eggs. A slight climate change could cause an increase in the tick population, lengthen the seasonal transmission period and displace distribution further North (Randolph 2001). Fortunately, for certain diseases, such as tick-transmitted encephalitis, the projected climate change will keep the focuses of this disease in Spain even further away.

Ixodes ricinus (on the Cantabrian coast, the Cameros mountains in the La Rioja region and in some isolated populations in the Guadarrama mountains and northern Cáceres) is very sensitive to climate warming, and the models project that this species would surely disappear from the country, although relictic populations could remain in the colder areas in Asturias and Cantabria. *Rhipicephalus sanguineus* does not depend directly on climate, but rather on the existence of housing development and types of periurban-rural construction that favour their development and colonisation. It is feared that African ticks (*Hyalomma marginatum*, *Hyalomma anatolicum*) might invade Spain, and these could be involved in the transmission of Crimean-Congo haemorrhagic fever.

16.3.3.3.2. Encephalitis. Lyme borreliosis. Rickettsiosis

The incidence of tick-borne encephalitis in Sweden has substantially increased since the mid-80s, and the distribution limits of the ticks *I. ricinus* have spread further North, due to temperature increase (Lindaren and Gustafson 2001).

Temperature increase could cause imported ticks to adapt to the new climate and to transmit diseases. Since the 90s, ticks of the species *R. sanguineus* have become established in southern Switzerland, and it has been demonstrated that these are infected rickettsia that causes Mediterranean spotted fever and Q fever (Bernasconi *et al* 2002).

16.3.3.4. Diseases transmitted by rodents

16.3.3.4.1. Transmissibility

Rodents can shelter other vectors such as ticks and fleas (*Xenopsylla cheopis*, *Ctenocephalides felis ....*) that transmit the plague and murine typhus. Furthermore, they can act as intermediary hosts or reservoirs of several diseases such as leptospirosis, haemorraghic viral fevers (Junin, Machupo, Guaranito, Sabia, Lassa), hantavirus, hymenolepis infection….

Both the population of wild rodents and the possibility of contact between rodent and human in urban areas is very much influenced by environmental changes. After years of drought, which could reduce the number of natural predators on rodents, there would be rainfall that would increase available food (seeds, nuts, insects), which would lead to an increase in the rodent population.

16.3.3.4.2. Hantavirus

In the South of the United States, there was an outbreak of a very serious epidemic of human hantavirus at the beginning of the 90s, associated with an unusual increase (up to 10 times) in the natural hantavirus reservoir rodent population (*Peromyscus* sp). The cause was the aforementioned climate change (Wenzel 2004).

In Spain, hantavirus has been detected in foxes and rodents and in human sera.

16.4. MOST VULNERABLE AREAS

16.4.1. Extreme temperatures

The areas most vulnerable to the thermal extremes expected ought to be identified with the use of different parameters. On one hand, we should consider the areas in which, according to different scenarios, greater frequency and intensity of thermal extremes are expected (see chapter 1). Furthermore, it is known that the biggest impact is on the older age groups (WHO 2004), and the greatest impact will therefore be in the places with a higher population of persons over 65 years of age, and this proportion is usually lower in the big cities. An example of this is the province of Soria, where 26.9 % of the population is over 65, whereas in Madrid, this figure only reaches 14.2%. Finally, we must consider adaptation to heat, as well as the different socioeconomic patterns and infrastructures available in each area (García-Herrera *et al* 2004)

16.4.2. Air pollution

Different studies have shown that the elderly, people with delicate health, suffering from chronic bronchitis, asthma, cardiovascular diseases, diabetes (Bateson and Schwartz 2004) and children, are among the most vulnerable groups (Tamburlini *et al* 2002). With regard to air pollution by ozone, the risk group would be made up of children, young people and adults, because these spend more time in the open air. If, besides, these people are doing intensive exercise (sports, work, play), the frequency and intensity of respiratory disorders increase, and consequently, the degree of risk. Children constitute a special risk group, because their respiratory systems are not fully developed, because they spend more time outdoors and because they breathe in more air per unit of weight than adults.

Furthermore, socioeconomic level has been related to the degree of impact of air pollution on health. Thus, a higher number of deaths due to respiratory causes has recently been described in Sao Paolo, Brazil (Martins *et al* 2004), and in Hamilton, Canada (Jerret *et al* 2004) among people with lower socioeconomical conditions . These differences could be due to different exposures (people from higher social classes live in less polluted places), to differences in the state of health (poverty is associated with illness, chronic bronchitis, for example), and to the fact that people with less financial resources could be more susceptible or vulnerable (poorer diet, worse housing conditions). The previous results, however, have been more related to primary pollutants such as CO and SO_2. As ozone is a secondary pollutant, the more exposed areas may be far from the emission points (Lipfert 2004).

16.4.3. Infectious diseases

Due to the proximity of the African continent, which is a place of obligatory transit for migratory birds and people, and to climate conditions, similar to those in areas with transmission of vector-borne diseases, Spain is a country in which these diseases could be boosted by climate change. But for the establishment of real areas of endemicity, a combination of factors would be needed, such as the mass and simultaneous arrival of animal or human reservoirs or the deterioration of socio-health conditions and of the Public Health services.

The vector-borne diseases that can hypothetically be influenced by climate change and emerge or re-emerge in Spain are shown in table 16.5:

Table 16.5. *Vectors-borne diseases that could be potentially ingluenced of climate change*

Disease	**Agent**	**Vector**	**Clinical pattern**
Dengue	Flavivirus	mosquito	Haemorrhagic viral fever
West Nile	*Flavivirus*	mosquito	Encephalitis
Crimean-Congo fever	*Nairovirus*	tick	Haemorrhagic viral fever
Tick-borne encephalitis	*Flavivirus*	tick	Encephalitis
Rift valley fever	*Phlebovirus*	Mosquito	Haemorrhagic viral fever
Boutonneuse fever	*Rickettsia conorii*	tick	Spotted fever
Murine typhus	*Rickettsia typhi*	flea	Typhoid fever
Lyme borreliosis	*Borrelia burgdorferi*	tick	Arthritis, meningitis, carditis
Endemic relapsing fever	*Borrelia hispanica*	tick	Fiebre recurrente
Malaria	*Plasmodium sp.*	mosquito	fiebres palúdicas
Leishmaniosis	*Leishmania sp*	flebotomo	kala-azar

Europe has warmed by around 0.8ºC in the last 100 years, but not in a uniform fashion, as the biggest increase has taken place in the North of the continent. If this tendency continues, it is likely that the high death rate of vectors in winter will decrease. It is harder to make predictions about rainfall, although winters will probably be more humid and summers drier. If the South were to become drier, wetlands would diminish, leading to a reduction of mosquito breeding places; other breeding grounds would appear, however, with the greater amount of stagnant waters produced as bodies of water, or rainwater deposits used by farmers dry out.

Predictions of change in Spain indicate rainier and warmer winters followed by hot, dry summers, which are favourable conditions for the establishment and proliferation of vectors. There would be a possible risk of the import and establishment of tropical and subtropical vectors adapted to survival in cooler and drier climates (for example, *A. albopictus*).

16.5. MAIN ADAPTIVE OPTIONS

16.5.1. Extreme temperatures

Numerous factors can have an influence on the impact of thermal extremes on the population and therefore, on adaptation to extreme events. Firstly, meteorological factors at local scale affect the occurrence of determined thermal extremes. Thus, for instance, the synoptic conditions that caused the heat wave in Madrid and Lisbon during the summer of 2003 were different in both places (García-Herrera *et al* 2004).

As the group most affected by thermal extremes appears to be the over 65s, any adaptation measures will need to be based on the population of each place. Factors associated with economic and cultural development can also condition the impact of thermal extremes. For example, heating systems have clearly mitigated the effects of cold spells, in spite of the associated increase in emissions of greenhouse gasses (Wilkinson *et al* 2001) and air conditioning systems have had the same effect during heat waves (Curriero *et al* 2002).

Although the ageing population is undoubtedly the most affected group, other groups, comprising people with different pathologies can also be negatively affected, and their pathologies exacerbated. The experience of 2003 showed us that apparently healthy people have died as a result of heat when carrying out activities such as sports in the open air at the hottest times of the day.

To this must be added the need to inform the population of the basic measures to be followed during thermal extremes, and to correctly train and adapt the health services in relation to possible increases in the pathologies associated with heat waves and cold spells. There is a need for *in situ* warning systems for possible thermal extremes. Each city needs to develop different systems based on their specific meteorological conditions, on the response by their own demographic distribution, infrastructure, social composition and hospital resources.

Unlike cities in the United States, European cities are unprepared for heat waves. In some European cities, the warning plan consists of weather forecasts, and only provides passive information to the general public and to the local safety institutions. Only Lisbon and Rome have implemented effective adaptive measures (Pirard 2003; WHO 2004). These systems are based on the fact that weather forecasts have a high degree of reliability – 24 – 48 hours before the thermal extreme, which means that there is enough time to mobilise a previously organised network. Thus, for example, in Philadelphia a warning is given through the media and a “hotline” is set up, the involvement of the neighbours and of the social services is brought to bear, and measures are implemented aimed at reinforcing emergency medical services and facilitating access for the elderly to places with air conditioning. These systems have proven to be efficient in the short term and could constitute a suitable long-term adaptation strategy for the population (Keatinge 2003).

Along these lines, an important adaptation strategy involves appropriate town planning aimed at mitigating urban heat island effects, along with the construction of bioclimatic buildings that guarantee the comfort of the inhabitants through minimum energy consumption.

16.5.2. Air pollution

As indicated by the United Nations Economy Commission for Europe (UNECE 2003), scientists and politicians should stop treating air pollution and climate change as different problems, because both are very closely related and are due to a great extent to the increased use of fossil fuels.

One of the first measures to be implemented should be the setting up of an air quality monitoring system (including information on meteorology, pollen and spores) and a public warning system for situations of increased levels. Legislative measures should also be implemented in order to establish certain air quality standards and emission restrictions aimed at protecting citizens’ health. The European framework facilitates the implementation of both these measures in our country, but effective policies are required in order to attain an integral systems comprising the different sectors involved: environment, public health, transport, industry, etc...

The most important measure involves reducing emissions of pollutant gasses. This in turn involves implementing strategies in the transport, town planning and industrial sectors based on the efficient use of energy and the progressive use of renewable energy sources.
Another measure could be the implementation of programmes aimed at reducing the risks of forest fires and exposure to allergenic pollen (Casimiro and Calheiros).

The previous measures ought to be complemented (McMichael AJ and Githeko AK 2001) with actions for health education and the promotion of healthy habits, including efficient and responsible energy use and information for public safety (for instance, informing of days with high levels of ozone).

One last aspect that ought to be highlighted is the need for citizen involvement in order to solve many of these problems. Environmental and health awareness should be promoted among the public, and common active participation in determining and problems and needs should be ensured, along with planning and action processes. Environmental health problems are related to the pattern of development in our country, as in other European countries (like, for example, the uncontrolled use of electric energy, drinking water, housing development, the use of private cars as the mains means of transport, etc). Consequently, the solution of these problems depends on big changes in lifestyles which affect large sectors of the population.

In short, future changes should be based on the contribution by all the sectors, that is to say, decisions by politicians, legislative changes, actions by the experts, education and information, decisions by the consumer, etc., aimed at promoting clean technologies, reduced use of fossil fuels, and the use of products that cause less pollution.

16.5.3. Infectious diseases

Recognition of the risk at official level is fundamental. We must be vigilant and not underrate the risk, and climatic data and statistics on infectious diseases should be collected in order for the early implementation, in cases of alert, of appropriate Public Health campaigns aimed at reducing the vulnerability of the population to infectious diseases, through strategies based on vaccination, vector control and water treatment (McCarthy 2001; Hunter 2003).

16.6. REPERCUSSIONS FOR OTHER SECTORS

16.6.1. Extreme temperatures

The aforementioned adaptive options clearly involved different sectors. In the first place, the meteorological information must be sufficiently reliable at local scale in order for the intervention plans to be effective, both in the detection of heat waves and cold spells and in determining their intensity and duration.

The insurance sector, in relation to both health and deaths, will be affected by an increase in the number of hospital admissions and by the costs associated with increased deaths.

The demand for energy, fundamental in air conditioning systems, will be affected by an increase in the needs of the population and of health centres, as has been described in the pertinent chapter.

In spite of the economic cost of the plans of action described, in the strict cost-benefit sense, and following the example of the Philadelphia Plan, these are highly profitable, because an annual cost of 250,000 dollars is related to profits in avoided mortality of 117 million dollars per year (Kalkstein 2002).

16.6.2. Air pollution

The adaptation measures described in the previous point will have an impact on different sectors.

16.6.2.1. Climate sector

Reduced emissions of pollutant gasses, as these are of the same origin as greenhouse gasses, would positively affect emissions of CO_2 and of other gasses into the atmosphere. This would lead to a deceleration of global warming.

16.6.2.2. Sector energía

More efficient energy use and the introduction of clean energy will reduce the use of fossil fuels, and consequently, will reduce emissions of SO_2, CO and NO_2.

16.6.2.3. Agriculture sector

The introduction of species with a high allergenic capacity in agriculture should be assessed, along with the treatment of these, particularly in crop fields close to human settlements. We should take into consideration the possible use of pesticides aimed at eliminating species with allergenic capacity, and possible repercussions upon human health, due to direct application, environmental exposure or exposure through foodstuffs.

The hypothesis that the consumption of antioxidant foods, with vitamin C, vitamin E and beta-carotene, like citrus fruits, carrots or nuts, and in general, all fruits and vegetables, protects against the effects of photochemical pollution (in particular ozone) may lead to increased consumption thereof being recommended. This would affect agricultural policies.

16.6.2.4. Forestry sector

Evidence of health risks caused by the emission of particles and gasses resulting from combustion should lead to increased protection of forests aimed at preventing forest fires.

16.B.6.5. Tourism sector

Measures aimed at attaining cleaner air and a healthier environment, together with models of good environmental practice, may also help to establish a system of ecologically sustainable quality tourism.

16.6.2.6. Health sector

An important question involves the beneficial secondary effects of mitigation policies. Actions aimed at reducing emissions of greenhouse gasses will probably lead to improvements in the health of the population (McMichael and Githeko 2001).

In an article in the review Lancet during the debate on the contents of the Kyoto Protocol, (Working Group on Public Health and Fossil-Fuel Combustion 1997) an evaluation was made of the possible short-term impact on human health of emission control, that is, without waiting to see the consequences in relation to the mitigation of climate change. This study compared what would happen, with regard to the effects of exposure to particles in suspension, if world energy policies were to continue in the same way as up to 1997, or if they changed to a scenario of emission control policies aimed at avoiding global warming. From the year 2000 to 2020, the different rates of exposure to particles could mean a difference of 700,000 deaths per year. Only in the United States, the number of avoidable deaths would be equivalent in magnitude to all the AIDS-related deaths or all those caused by hepatic diseases.

In another study, an estimate of the benefits of reduced air pollution in four north or south American cities (Santiago de Chile, Sao Paulo, Mexico and New York) indicated that if the available technologies were adopted for reducing air pollution and global warming, there would be 65,000 deaths less and a reduction of the associated cases of bronchitis and restricted activity (Cifuentes *et al* 2001).

These results illustrate the benefits, at local scale and at a closer scale in time, of policies for the reduction of emissions of the gasses that cause global warming. These figures, however, should be evaluated with care, and only taken as indicators, given the existing assumptions and doubts involved in the estimates. It has been demonstrated, however, that the use of renewable energy sources can help to reduce emissions, while at the same time, constituting an accessible source of energy for a large sector of the population that has current access to clean energy sources (McMichael and Githeko 2001).

Strategies by the transport, environment and health sectors, involving the use of the bicycle and walking as means of transport, will lead to increased moderate physical exercise in a large segment of the population that at present has sedentary habits, and this will have favourable consequences for public health (Haines *et al* 2000).

16.6.3. Infectious diseases

The biggest repercussion of the reintroduction or dissemination of vector-transmitted diseases would be seen in the Tourism sector. An increase in these disease in tourist areas would dissuade the tourist from choosing these destinations, with the resulting consequences.

The Agriculture and Forestry sectors are intimately correlated with the habitats and ecosystems in which vectors breed.

16.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

16.7.1. Extreme temperatures

Perhaps it is this aspect related to effects upon health, and in particular to thermal extremes, the one that presents the highest degree of uncertainty.
Firstly, there are the aspects related to the climate models themselves, which are described in the corresponding chapter. To this we must add the clearly local nature of the behaviour of extreme temperatures on the Peninsula, as has been seen in recent studies (Prieto *et al* 2004). Another key factor involves the determination of possible demographic scenarios, above all related to demographic distribution in the over 65 age group, a target group for the effects of heat waves and cold spells (WHO 2004). Furthermore, the possible impacts dealt with here depend on social, economic, technological, cultural, political and biophysical factors, the evolution of which is unknown. The implementation of prevention plans such as the one previously described, the resources involved and the effectiveness of these, will be decisive in determining the direct effects upon the health of the population.

The health sector also presents an added disadvantage, basically related to the lack of data on the effects of thermal extremes on morbidity and mortality. Current data registers do not allow for measures to be taken in real time and several months (even years) must elapse before these data become available to researchers. Without a flexible and reliable database system, any research becomes particularly complicated and any dose-response model based on this information will be biased as a result of this.

The uncertainties expounded in this section should not be used by the actors involved as an excuse for shortcomings in the adoption of measures aimed at minimising the effects of temperature extremes. The logical uncertainty relating to future climate scenarios and the effects of these on health does not mean that these effects will not occur, and an example of the effects of temperature on the excess mortality recorded in Europe during the summer of 2003, which was briefly dealt with in section 3 of this chapter.

16.7.2. Air pollution

There is a series of general uncertainties regarding the process of *climate change* and associated predictions that has been commented upon elsewhere. With regard to the effects of air pollution upon health and the relationship between these and climate change, there exists a series of specific uncertainties. Two elements that could determine this impact in the future are:

Future emission scenarios. These could be based on estimate of economic or population growth, but also upon restrictions established through legislation or accords. In both cases, it is very difficult to make estimates, due to the reality of the situation, in relation to the evolution of greenhouse gas emissions in Spain, and because the levels agreed upon by the Spanish Government in relation to compliance with the Kyoto Protocol have been well surpassed.

The sensitivity and vulnerability of populations. There is a tendency in our country towards ageing of the population, which would lead to a bigger impact, due to the greater susceptibility of the elderly and their delicate state of health. Furthermore, there is still much uncertainty regarding the quantitative calculation of the risk associated with most pollutants. For particles, a linear concentration-response relationship has been defined, but less knowledge exists of the form of the relationship with other pollutants. There will be a particular need for evidence of the impact of ozone on health, given the unpredictable increase, at least in the episodic sense, of this pollutant resulting from climate change.

16.7.3. Infectious diseases

Apart from the observations associated with periodic natural oscillations, there has been no irrefutable proof that the slight climate change in the last few decades has increased the global risk of transmission of diseases transmitted by arthropods, but there is sufficient scientific evidence to suspect so.

Mathematical predictions indicate increased risk provided that the climate change continues to occur, which seems evident to practically everyone. Some experts, however, are sceptical with regard to these predictions, because the natural history of diseases transmitted by arthropods is complex, and other factors besides climate interfere, which means that we should avoid simplistic analyses.

Apart from climate change, many other factors can influence the epidemiology of vector-borne diseases: atmospheric composition, housing development, economic and social development, international trade, human migration, industrial development, land use-irrigation-agricultural development (Suthers 2004). The recent re-emergence of many of these diseases in the world could more likely be attributed to political and economic changes, and to changes in human activity, rather than to climate change.

Climate alone would not constitute a sufficient basis for the establishment of endemic foci in Spain. A sufficient number of simultaneously infected individuals would be needed to constitute an infection reservoir. Semi-immune immigrants can serve as hosts to parasite for many months with almost no symptoms, and can act as effective reservoirs of diseases. Although increased tourism and immigration from endemic areas can import cases, these would not be sufficient in number to start an epidemic, and could, at worst, originate very local foci of self-limited transmission and cases of airport infections (Hunter 2003).

16.8. DETECTING CHANGE

16.8.1. Extreme temperatures

It is vital to avail of morbidity and mortality evolution models based on sufficiently long time series in order to detect in advance possible changes in patterns and behaviour. The anomalous evolution of a time series cannot be detected if the expected behaviour of this is unknown, and, what is more important, if these expected data are not compared with real data. There is a noteworthy need to streamline and increase the degree of reliability of morbidity and mortality records, not only as an indicator of extremes, but also as the basis of any subsequent research. Thus, these records could be used to assess the effectiveness of any intervention in relation to predicted heat waves or cold spells.

16.8.2. Air pollution

Detecting climate change and attributing the effects of this on health require a monitoring system aimed at the early detection of effects (Kovats *et al* 2000). This system should provide quality data on meteorology, environment, health and demography. The health-related data eligible to form part of these systems should satisfy the following prerequisites (McMichael 2003):

- Evidence of sensitivity to climate changes
- Relevance for public health due to the health statistics they represent
- Feasibility of the information gathering system

In our country, there is no *epidemiological surveillance system of the effects of air pollution.* Different air quality monitoring programmes currently exist, managed by the central government, and in the regional autonomies, by the departments of the environment. These systems are generally not integrated into the warning systems or public health services. This should be a priority for the near future in our country, and not only in relation to the detection of effects associated with climate change. This surveillance system should include daily information on the levels of air pollution, on meteorological variables and on health variables such as deaths (total and due to specific causes), on the number of hospital admissions due to cardiovascular and respiratory causes, and if possible, information on emergency hospital admissions. If the latter information were not available, a series of emergency services could be chosen as an indicator. The corresponding information should also be obtained in relation to demographic structure, socioeconomic level and quality of habitat and of health services.

In order to reach the objectives of a surveillance system, this should generate and keep records, and, very particularly, it should produce pertinent and representative information for use in the planning, development and evaluation of public health measures.

A complementary alternative to the previous one consists of *periodic evaluations of the impact on health* of air pollution and the possible relationship between this and climate change (WHO 2000). In Europe, the programme APHEIS (2001 2002) evaluated the impact of air pollution on health in 26 cities in 12 European countries. The total population covered by this impact evaluation is around 39 million European inhabitants. As a whole, for the 19 cities with available data on PM10, a 5µg/m3 reduction of PM10 levels would cause a decrease in long-term mortality by 5,000 deaths yearly, of which 800 would be short-term deaths. This evaluation provides a quantitative calculation of the potential benefits of a reduction of pollutant levels.

16.8.3. Infectious diseases

As has been mentioned, there is no irrefutable evidence that the climate change that has occurred to date has substantially modified the epidemiology of vector-transmitted infectious diseases.

The collection of survey data and timely research in the “climate - vectors - man” triangle of interaction would have the advantage of providing an extremely useful database. These systems should also include variables such as demographic, economic and environmental ones, because changes in the epidemiology of infectious diseases are more likely to be the result of these than of climate change itself.

There should be studies of the prevalence of certain diseases, such as flaviviriasis, using seroprevalence studies in risk populations. Furthermore, vector populations should be studied for the early detection of new species and to determine the geographic dispersion of the populations of recently detected foreign species (as is the case of A. albopictus).

These studies should be sufficiently effective and accurate in order to detect minimum changes in health. Unfortunately, current vector monitoring systems do not fulfil to these requirements.

Essentially, the detection of change involves the detection of pathogenic micro-organisms: - in the vectors (dengue or West Nile encephalitis viruses in mosquitoes); - in the natural reservoirs (rodents, birds or horses); and in humans (both the asymptomatic inhabitants of risk areas and patients admitted for treatment with compatible pathologies, through blood analysis, sera, cerebrospinal fluid…etc.).

16.9. IMPLICATIONS FOR POLICIES

16.9.1. Extreme temperatures

Although we have insisted throughout his chapter upon the local nature of prevention or action plans, these should be governed by general policies that serve as a framework for the development of these activities.
Following the WHO stance on climate change (WHO 2003), the medium-term development of the following measures is considered to be necessary:

1. Facilitating the organisation of interdisciplinary forums between politicians and experts aimed at identifying needs and courses of action.
2. Facilitating the creation of multidisciplinary teams for informing the public of potential health risks related to thermal extremes and the implementation of measures aimed at mitigating the effects of these.

3. Facilitating the design of mechanisms for the early evaluation of plans of action in order to increase efficiency.

In the short term in Spain, there is a need for public health plans of action based on early warning systems allowing risk situations to be identified before these occur. In this sense, meteorological information is fundamental. It is a question of predicting excessive morbidity and mortality within a time period that allows for rapid response. Morbidity and mortality records, as one of the first elements in a chain of actions, should be flexible and reliable. No warning plan can be based on real increases in morbidity and mortality if access can only be gained to these data weeks or even months after these excesses have occurred. Furthermore, the implementation of hospital management actions aimed at adjusting the health services to determined situations has been seen to be a vital part of action policies. Lastly, total co-ordination with the social services is required, fundamentally with those working with the less favoured social classes, in order to articulate the aforementioned plans of action.

In this sense, the Comunidad de Madrid (regional autonomy) intends to set up a “heat wave warning and prevention plan” for the summer of 2004. This plan would include a meteorological warning and surveillance system intended to provide a warning several days before the event takes place, which would allow for early warning for the population and for the social and health services. The actions include assistance for the population subjected to particular risk, and special surveillance for the elderly in order to guarantee accessibility to health services and a social support plan dealing with needs related to food, healthcare, mobility and climatic comfort.

16.9.2. Air pollution

1. Application and follow-up of European Directives on Air Quality, including the implementation of procedures and techniques for the correct measurement and continuous recording of pollutant levels.
2. Co-ordination between the different Departments involved (Environment, Heath, Transport, Town Planning, Public Works, Agriculture).
3. Inter-territorial integration and co-ordination between central Government and Regional Autonomies.
4. Establishment of integrated policies for surveillance and protection of public health, including information on environmental risks.
5. Actions aimed at reducing emissions related to fossil fuels.
6. Implementation of activities aimed at increasing public awareness and participation in aspects related to climate change, involving a communication strategy for ensuring information and presenting this in an understandable way and guidelines on how it should be used (McMichael 2003).
7. Lastly, it is necessary to invest in studies and research in order to reduce the uncertainties involved in decision-taking (McMichael 2003).

16.9.3. Infectious diseases

In Spain, there is no specific legislation adapted to the current needs of vector control. Apart from mosquito control programmes in Spain, there are also regulations involving the inspection, certification and quarantine applied to the products from endemic areas that could transport vectors, such as used tyres or exotic plants like the luck bamboo tree.

Very concisely, we could summarise the implications for policies as: promoting and developing Surveillance and Control Programmes for vector-transmitted diseases, through sufficient and stable funding. –These programmes should, in turn, be co-ordinated with other surveillance programmes at national level. Uniting research among the different research groups working in different fields and belonging to different areas, such as veterinary, epidemiology, entomology, zoology and medicine. Providing appropriate facilities for reference laboratories and for hospital laboratories for accurate diagnosis of vector-borne diseases. – Disseminating existing knowledge through specific training courses in Spanish universities.

16.10. MAIN RESEARCH NEEDS

16.10.1. Extreme temperatures

The main research needs should be basically aimed at eliminating, to the greatest possible extent, the aforementioned uncertainties. It will therefore be necessary to analyse atmospheric conditions at lesser meteorological scale in order to establish with sufficient warning the production, intensity and duration of an extreme thermal event, at least in each province.
There should be more in-depth study of the mechanisms of physiological adaptation and of the role played by socioeconomic variables in adaptation processes. Studies of the temporal evolution, according to different time periods, of the behaviour of morbidity and mortality in recent years, according to thermal extremes are considered to be appropriate with regard to establishing this type of tendencies.

There is also a pressing need for research at local scale into the behaviour of morbidity and mortality associated with extreme temperatures, with particular emphasis on the influence of these extremes on hospital admissions according to specific causes and age groups, in order to establish, to the greatest possible extent, the behaviour of each population group in relation to temperature. Finally, we ought to evaluate the effectiveness and functioning of the action plans for thermal extremes wherever these have been established, and use these experiences for implementing new ones. All these initiatives should be set within a European framework, in order for their objectives, quality and effectiveness to be compared with determined common references for all the neighbouring countries.

16.10.2. Air pollution

It is generally agreed that research into impacts upon health should have an international perspective and be based on an international network of scientists. On one hand, we are dealing with situations on a worldwide scale which have no borders, and we should therefore provide a maximum guarantee of information exchange, in order to assess differences in environmental, socio-demographic and health situations between the different geographic locations and populations. It is generally a question of assessing the possible impacts on health associated with each one of the phenomena constituting climate change. In the specific field of the possible effects of *air pollution* related to climate change, the fundamental needs are:

- Establishing surveillance and monitoring systems including appropriate information on meteorology, environment, health and socio-demography, for the early detection of changes and in order to obtain data for further study.

- Carrying out epidemiological studies aimed at evaluating the impact of ozone, fine particles and other pollutants related to climate change and the influence of these upon health. These studies should provide proof of the effects of these pollutants, including the dose-response relationship and factors that could modify its effects (greater susceptibility of certain groups of people, and protection factors, such as, for example, increased antioxidant capacity through diet).

- It will also be necessary to carry out epidemiological studies aimed at assessing the possible benefits of actions for mitigating climate change.

- Developing models for predicting the possible effects on health of the expected changes in climate and air quality. These models should include predictions of the future tendencies of air pollution, changes in population characteristics and variations in meteorological and climatic phenomena. These predictions ought to be validated in a continuous manner, by means of comparison with data from the surveillance system.

16.10.3. Infectious diseases

The main lines of research should focus on: -the design of models that correlate climatic parameters with the incidence of infectious diseases (rather than models based on risk areas and populations). –The design of validation models between present and past climatic data and the frequency of infectious diseases transmitted by vectors.- Sampling of populations, vectors and reservoirs. –Studies of changes in the distribution or changes in the frequency of transmission of the diseases most likely to be influenced: dengue and other flavivirus, malaria, leishmaniasis, rickettsiosis….-Development of new rapid diagnosis tests.

In relation to this, an initial European initiative is starting to take its first steps. The Sixth Framework Programme, under the auspices of the European Union, includes among its priority research themes emerging diseases and in particular the relationships between these and “Global Change and Ecosystems”. Following the appeal made by the European Research Commission in this respect, requesting an expression of interest in the subject, in 2004 a proposal on Emerging Diseases in a Changing European Environment was accepted (EDEN network). This international network comprises a consortium of European researchers belonging to 33 countries, including Spain, whose objective is to anticipate the effects that environmental changes could have on public health in Europe, and to co-ordinate the pertinent research in a common scientific framework divided into these five main areas: Landscapes; Biotopes and Habitats; Bionomics of Vectors and Parasites and Competition; Public Health and Human Activities; Animal Reservoirs; Integration and Management of Databases. For the next five years, this network will be dedicated to identifying, evaluating and classifying the European ecosystems and environmental conditions associated with global change that could affect the spatial and temporal distribution and the dynamics of pathogenic agents. To this end, predictive models of emergence and dispersal will be developed, including global and regional prevention, early warning systems, surveillance, monitoring of tools and description of scenarios. The diseases selected for this research are West Nile encephalitis, Lyme borreliosis, encephalitis transmitted by ticks, Rift valley fever, Dengue, Malaria and leishmaniasis.

16.10.4. Conclusion

The authors of this chapter insist upon the implementation of an *evaluation of the possible impact of climate change on health in Spain***,** as has been done in other countries like the United States (Bernard *et al* 2001) the United Kingdom (Anderson *et al* 2001) or Portugal (Casimiro and Calheiros 2002). This evaluation should include a quantitative estimate of impacts upon health, taking into consideration the different scenarios of climate change and predictions of the demographic structure of our country. In this sense, the World Health Organisation has developed a methodology for the assessment of the vulnerability of human health and the adaptation of human health to climate change (Kovats *et al* 2003).
This evaluation would fulfil the following *requirements:*

- To establish an explicit mandate of the decision takers in public health and/or environmental policies. Indeed, the national governments have the responsibility of implementing these, according to agreements by the United Nations at the Climate Change Summit (UNO 1992)
- Multidisciplinary perspective, with the use of new analysis and interpretation techniques. This should include not only the disciplines directly related to the theme (environmental health,

epidemiology, climatology, clinical medicine, toxicology), but should also consider other disciplines such as sociology, psychology and economy.

- Priority should be given to specific problems in the different regions of Spain, and particular attention ought to be paid to specific local problems (for example, temperature increases in certain parts of the Peninsula, dust storms from the Sahara in the Canary Isles, etc.).
- The purpose of the evaluation of the impact upon health should be aimed at the prevention of the disease and at the evaluation of the consequences of the measures taken, including public health actions.

The evaluation should identify the areas with the highest levels of uncertainty, consider research needs and be linked to the surveillance and monitoring systems to be created (McMichael 2003).

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ANNEX II

List of acronyms used in the text

Original acronym	Meaning in Spanish and in the original language	Acronym in Spanish
AGROSEGURO	Agrupación Española de Entidades Aseguradoras de los Seguros Agrarios Combinados SA	AGROSEGURO
AO	Oscilación del Ártico (*Arctic Oscillation*)	AO
AOGCM	Modelo de circulación general acoplado océano-atmósfera *(Atmosphere-Ocean Global Circulation Model)*	MCGA-OA
APHEA	Estudio europeo sobre el impacto agudo de la contaminación atmosférica en la salud (*Air Pollution and HEAlth*)	
APHEIS	Sistema de Información sobre contaminación atmosférica y la salud en Europa	
ART	Transferencia alternativa de riesgos *(Alternative Risk Transfer)*	
ATS	Aporte de agua del trasvase Tajo-Segura	ATS
BBVA	Banco Bilbao-Vizcaya-Argentaria	BBVA
BP	Antes del tiempo presente (*Before Present*)	
CAP	Política Agraria Común *(Common Agricultural Policy)*	PAC
CBD	Convención sobre la diversidad biológica (*Convention on Biological Diversity*)	CDB
CCAA	Comunidades Autónomas	CCAA
CCS	Consorcio de Compensación de Seguros	CCS
CEDEX	Centro De estudios y Experimentación de Obras Públicas (Ministerio de Fomento)	CEDEX
CEH	Centro de Estudios Hidrográficos	CEH
CITES	Convención Internacional sobre el Comercio con Especies Amenazadas	CITES
CLH	Compañía Logística de Hidrocarburos	CLH
CNE	Comisión Nacional de la Energía	CNE
COADS	Base de Datos de Atmósfera-Océano (*Comprehensive Ocean Atmospheric Data Set*)	
CRU	Unidad de investigación sobre el clima, Universidad de East Anglia (*Climate Research Unit*, University of East Anglia)	
CSIC	Consejo Superior de Investigaciones Científicas	CSIC
CTEI	Comisión Técnica de Emergencia por Inundaciones	CTEI
DC	Después de Cristo	DC
DDC-IPCC	Centro de Distribución de Datos del Panel Intergubernamental para el Cambio Climático (*Data Distribution Center of the Intergovernmental Panel on Climate Change*)	

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DGB	Dirección General para la Biodiversidad	DGB
DGCN	Dirección General de Conservación de la Naturaleza	DGCN
DGOH	Dirección General de Obras Hidráulicas	DGOH
DGPEM	Dirección General de Política Energética y Minas	DGPEM
DGSFP	Dirección General de Seguros y Fondos de Pensiones	DGSFP
DMA	Directiva Marco del Agua	DMA
DSSAT	Sistema de transferencia de datos sobre agrotecnología (*Decision Support System for Agrotechnology Transfer*)	
EA	Patrón del Atlántico Este (*East Atlantic Pattern*)	
EA/WR	Patrón del Atlántico Este/Rusia Oeste (*East Atlantic/West Russian pattern)*	
EAN	Red Europea de Aeroalérgenos (*European Aeroallergen Network*)	
ECA	Evaluación del clima en Europa (*European Climate Assessment*)	
EEA	Agencia Europea del Medio Ambiente (*European Environmental Agency*)	AEMA
EECC	Estrategia Española de Lucha contra el Cambio Climático	EECC
EEDS	Estrategia Española de Desarrollo Sostenible	EEDS
EEUU	Estados Unidos de América	EEUU
EMECAS-EMECAM	Estudio multicéntrico sobre los efectos de la contaminación atmosférica en la salud en España	EMECAS-EMECAM
ENACW	Masa de agua del Atlántico Norte Centro-Oriental (*Eastern North Atlantic Central Water*)	
ENAGAS	Empresa Nacional del Gas	ENAGAS
EPN	Red Europea de Fenología (*European Phenology Network*)	
ETP	Evapotranspiración	ETP
EUA	Eficiencia en el uso del agua	EUA
EV	Evaporación	EV
EXAMINE	Exploitation of Aphid Monitoring In Europe	
FAO	Organización de las Naciones Unidas para la Alimentación y la Agricultura (*Food and Agriculture Organization*)	FAO
FSUE	Fondo de Solidaridad de la Unión Europea	FSUE
FWI	Indice meterorológico de peligro de incendio (*Fire weather index*)	
GCM	Modelo de circulación general *(Global Circulation Model)*	MCG

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GEI	Gases de efecto invernadero (*Greenhouse effect gases*)	GHGs
GFDL	Laboratorio de dinámica de geofluidos (*GeoFluids Dynamics Laboratory*)	
GIS	Sistema de información geográfica (*Geographic information system*)	SIG
GISS	Instituto Goddard para estudios Espaciales (*Goddard Institute for Space Studies*)	
GLOBE	Conocimiento Global para el Beneficio del Medio Ambiente (*Global Learning to Benefit the Environment*)	
GLOBEC	Programa de investigación sobre la dinámica de los ecosistemas oceánicos (*Global Ocean Ecosystems Dynamics*)	
GNL	Gas natural licuado	GNL
GOOS	Sistema de observación del océano (*Global Ocean Observing System*)	
HAB	Programa de investigación sobre la proliferación de algas nocivas (*Harmful algal bloom*)	
IAOCSS	Resumen anual sobre clima y océano del Consejo Internacional para la Exploración Marina (*International Council for the Exploration of the Sea Annual Ocean Climate Status Summary*)	
ICC	Instituto Cartográfico de Catalunya (*Institut Cartográfic de Catalunya*)	ICC
ICES	Consejo Internacional para la Exploración Marina (*International Council for the Exploration of the Sea*)	
IEO	Instituto Español de Oceanografía	IEO
IFREMER	Instituto Francés de Investigación para la Explotación del Mar (*Institut français de recherche pour l'exploitation de la mer*)	
IGBP	Programa Internacional Geosfera-Biosfera (*International Geosphere-Biosphere Programme*)	
IGME	Instituto Geológico y Minero de España	IGME
IGN	Instituto Geográfico Nacional	IGN
IGPC	Programa Internacional de Ciencias de la Tierra (*International Geosciences Programme)*	
INE	Instituto Nacional de Estadística	INE
INITEC	Empresa Nacional de Ingeniería y Tecnología	INITEC
INM	Instituto Nacional de Meteorología	INM
INQUA	Unión Internacional para el Estudio del Cuaternario (*International Union for the Study of Quaternary)*	
IPC	Índice de Precios al Consumo	IPC

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IPCC	Grupo Intergubernamental de Expertos sobre el Cambio Climático (*Intergovernmental Panel on Climate Change*)	GIECC
ITC	Instituto Tecnológico de Canarias	ITC
ITGE	Instituto Tecnológico Geominero de España	ITGE
ITRDB	Base de Datos Internacional sobre Anillos de Creciemiento de Árboles (*International Tree Ring Data Bank*)	
IUCN	Unión Internacional de Conservación de la Naturaleza (The *World Conservation Union*)	UICN
JACUMAR	Junta Nacional Asesora de Cultivos Marinos	JACUMAR
JGOFS	Programa de investigación sobre los flujos de elementos en el océano (*Joint Global Ocean Flux Study*)	
LAI	índice de área foliar (*Leaf area index*)	IAF ó ISF
LBAE	Libro Blanco del Agua en España	LBAE
LFFMC	Contenido en humedad de los combustibles vivos finos (*Live fine fuel moisture content*)	
LIC	Lugar de Interés Comunitario	LIC
MaBP	Millones de años antes del presente	
MAPYA	Ministerio de Agricultura, Pesca y Alimentación	MAPYA
MIMAM	Ministerio de Medio Ambiente	MIMAM
MINER	Ministerio de Industria y Energía	MOPTMA-MINER
MMA	Ministerio de Medio Ambiente	MMA
MNCN-CSIC	Museo Nacional de Ciencias Naturales	MNCN-CSIC
MOPTMA	Ministerio de Obras Públicas, Transportes y Medio Ambiente	MOPTMA
MOPU	Ministerio de Obras Públicas y Urbanismo	MOPU
MPA	Red de áreas marinas protegidas (*Marine protected areas*)	AMP
NAO	Oscilación del Atlántico Norte (*North-Atlantic Oscillation*)	OAN
NAP-UNCCD	Programa de Acción Nacional contra la Desertificación (*National Action Programme to Combat Desertification*)	PAND
NDVI	Índice de vegetación normalizado (*Normalized Difference Vegetation Index*)	
NGO	Organización no gubernamental (*Non-Govermental Organization*)	ONG
NMM	Nivel medio del mar	NMM
NMMAPS	Estudio sobre el impacto de la contaminación atmosférica sobre la mortalidad y la morbilidad en Estados Unidos (*National Mortality and Morbidity Air Pollution Study*)	

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NOAA-CIRES	Administración Nacional para el Océano y la Atmósfera de EEUU-Instituto de Cooperación para la Investigación en las Ciencias Ambientales (*National Oceanic and Atmospheric Administration-Cooperative Institute for Research in Environmental Sciences*)	
OAPN	Organismo Autónomo Parques Nacionales	OAPN
OECD	Organización para la Cooperación y el Desarrollo Económico (*Organisation for Economic Co-operation and Development*)	OCDE
OMEL	Operadora del Mercado Eléctrico	OMEL
OPTIGES	Optimización de la gestión de los recursos hídricos de una cuenca (módulo incluido en el sistema AQUATOOL, desarrollado en el IIAMA de la UPV (Instituto de Ingeniería del Agua y Medio Ambiente de la Universidad Politécnica de Valencia).	OPTIGES
PAH	Hidrocarburos Aromáticos Policíclicos	HAP
PFER	Plan de Fomento de las Energías Renovables	PFER
PHN	Plan Hidrológico Nacional	PHN
PIB	Producto Interior Bruto	PIB
PIB a p.m.	Producto Interior Bruto a precios de mercado	PIB a p.m.
PM10	Partículas con un diámetro aerodinámico inferior a 10 μm	PM10
PM2,5	Partículas con un diámetro aerodinámico inferior a 2,5 μm; también se conocen como partículas finas	PM2,5
PYMES	Pequeñas y medianas empresas	PYMES
RCM	Modelo regional del clima (*Regional Climate Model*)	MRC
REA	Red Española de Aerobiología	REA
REE	Red Eléctrica de España	REE
RPA	Red Portuguesa de Aerobiología	RPA
SACRE	Seguimiento de Aves Comunes Reproductoras en España	SACRE
SAHFOS	Fundación Alister Hardy de Oceanografía (*Sir Alister Hardy Foundation for Ocean Science*)	
SCAN	Patrón de Escandinavia (*Scandinavian pattern*)	
SEO	Sociedad Española de Ornitología	SEO
SIMPA	Sistema Integrado para la Modelización de la Precipitación-Aportación	SIMPA
SOLAS	Programa de investigación sobre la dinámica en la superficie del océano en contacto con la atmósfera (*Surface Ocean – Lower Atmosphere Study*)	

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SRES	Informe especial sobre escenarios de emisión (*Special Report on Emission Scenarios*)	
SST	Temperatura de la superficie del mar (*Sea Surface Temperature*)	
UE	Unión Europea	UE
UKMO	Oficina Meteorológica del Reino Unido (*United Kingdom Meteorological Office*)	
UNECE	Comisión Económica de las Naciones Unidas para Europa (*United Nations Economy Commission for Europe*)	CENUE
UNEP	Programa de las Naciones Unidas para el Medio Ambiente (*United Nations Environment Programme*)	PNUMA
USDA	Departamento de Agricultura de los Estados Unidos (*United States Department of Agriculture*)	
USLE	Ecuación Universal de Pérdida de Suelo *(Universal Soil Loss Equation)*	
UVB	Ultravioleta-B (Ultraviolet-B)	UVB
VOC	Compuestos volátiles orgánicos (*Volatile Organic Compounds*)	COV
WCD	Comisión Mundial sobre Represas (*World Commission on Dams*)	
WHO	Organización Mundial de la Salud (*World Health Organization*)	OMS
WTO - OMT	World Tourism Organization - Organización Mundial del Turismo	OMT
WWF	Fondo Mundial para la protección de la vida salvaje (*World Wildlife Fund*)	

MINISTERIO
DE MEDIO AMBIENTE