# B

## Energy and industry-related issues

The work carried out under this task is discussed under the heading:

Energy; human settlement; transport and industrial sectors; human health; air quality; effects of ultraviolet-B radiation

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# III Energy; human settlement; transport and industrial sectors; human health; air quality; and effects of ultraviolet-B radiation

This supplementary report covers changes in knowledge of and insight into the impact of climate change on human settlement, energy, transport and industrial sectors, human health and air quality. The report also covers recent discoveries concerning the impacts of increased ultraviolet radiation from stratospheric ozone loss.

There have been many new studies reported in the last eighteen months. In human settlement, there has been more work on the implications of sea-level rise, and some important new findings have been made on the implications of soil shrinkage and swelling in the United Kingdom. In the energy area, there have been numerous studies both on demand and supply. New regional studies have also added depth to the understanding of potential variations in impacts. Apart from analysis of how industry might be affected by response strategies, however, there has been relatively little research on the direct impacts of climate change on industry or transport; the most important results come from a United Kingdom country study.

Knowledge of climate change on human health has been extended and confirmed with greater understanding of potential increases in disease during 'heat wave' and potential shifts in disease vector habitats with global warming, particularly in New Zealand and Australia. Diseases such as malaria, Chagas disease (trypanosomiasis), lymphatic filariasis, schistosomiasis, leishmaniasis, onchocerciasis (river blindness), dengue fever, and Australian and Japanese encephalitis could increase or be reintroduced in many countries as a consequence of global warming (WMO 1990). There is greater understanding of the mechanisms of the effect of temperature on air pollutants. Finally, recent studies have linked ultraviolet-B radiation (UV-B) to additional effects that had not been proposed previously. Immunosuppression has been demonstrated in peoples regardless of pigmentation, and new types of damage to the eye, deformations of the anterior lens and presbyopia, have also been linked to UV-B.

Strong impacts on marine organisms from conditions stimulating reduced ozone (ie enhanced UV-B) have been demonstrated in the laboratory. In the Antarctic, enhanced UV-B has been linked to a reduction of primary production rates of 6% to 12% from decreased photosynthesis. Studies were also undertaken on the biochemical and photochemical characterisation of representative species of the bacterioplankton in the southernmost region of Argentina (Ushaia, Beagle Channel, Lapataia and three lakes in Tierra del Fuego—Orce (1990)) New laboratory studies have expanded knowledge about which terrestrial plants are sensitive to increased UV-B.

Regional studies, including country impact studies of New Zealand (1990), the United Kingdom (1991), Mexico (1990) and Russia (1991), as well as a number of country studies prepared for the Asian-Pacific Seminar on Climate Change (Nagoya 1991) and a United States Department of Energy study covering four states in the interior of the US (MINK) have been released since the last IPCC WGII report. A summary of the UNEP impacts report covering five countries in the developing world (Brazil, Thailand, Malaysia, Indonesia, and Vietnam) is available now, and the full report should be available shortly.

## 1 Energy

Energy demands in lower latitudes are expected to increase, particularly in developing countries, as access to and need for air-conditioning grows. Higher latitude industrial countries can expect slight decreases in energy demand from decreased space heating. However, the overall cost of energy in some countries may rise considerably because of increased production costs as a result of climate change and permafrost thaw. Projections for Northern Russia indicate an increase of 20% in the calculated price of natural gas and oil resulting from a 2°C warming, although hydro-electric production could grow by 7–10% between 2000–2020 owing to increased river run-off (Yakovlev 1991). Biomass production, upon which developing countries depend for much of their energy needs, could be altered by climate change; better regional forecasts are needed to assess impacts on specific regions.

### *1.2 Energy consumption*

Space heating/cooling of buildings is one of the most climate-sensitive uses of energy, especially the use of electricity for residential and commercial air-conditioning and electricity plus other fuels for space heating. Two key questions are, first, the potential increases in the ownership and use of air-conditioning and how climate change might influence them and, second, the potential impact of climate change on availability of traditional biomass fuels and consequent changes in energy use. Studies in Argentina on the comfort requirements of local representative biotypes suggest a reduction in energy requirements for air-conditioning could result. Although usually smaller in total magnitude of energy demand, the use of electricity and fuels for irrigation pumping and use of fuels for drying of agricultural crops also can be significant weather-sensitive demands in some regions. Climate change has negligible direct effect on vehicle performance; however, transportation is sensitive to immediate impacts due to weather and may be indirectly sensitive to gradual shifts in activities in response to climate change and to greenhouse gas response strategies. Substantial impacts on traditional uses of energy in developing countries, such as cooking, are likely in response to shortages of supply.

### *1.3 Energy supply systems*

The main impact on supply discussed earlier was the potential for changes in hydro-electric power generation due to changes in water runoff. There are relatively few studies of most other potential impacts on supply.

The lifetimes of many energy supply facilities and of energy-using systems are comparable to or shorter than the time-scale for substantial changes in climate (UKDOE 1991). Changes in demand due to climate change appear to be small compared with potential changes due to other factors, such as economic and population growth, lifestyle and technology changes etc. Hence, adjustments in the energy supply system and in energy-using equipment to accommodate climate changes often can be made in the course of normal replacement. Adjustments in supply system planning to accommodate climate change should be feasible; costs will usually be small-to-moderate if the impacts of climate change and other determinants of demand are anticipated (Linder et al. 1989). However, the overall cost of energy in some countries may rise considerably due to increased production costs as a result of climate change and permafrost thaw. Projections for Northern Russia indicate an increase of 20% in the calculated price of natural gas and oil resulting from a 2°C warming (Yakovlev 1991).

Climate change could affect steam and nuclear electric power plants. They are vulnerable to curtailments of water supply for cooling and are moderately sensitive to increases in wet-bulb air temperature or water temperature, depending on the type of cooling system. Anticipation of climate extremes when designing plants can avoid many of the problems, but water supply during extreme drought depends on the overall water management situation in each basin. An example of potential problems with both steam electric and hydro-electric systems during drought was the event in the summer of 1988 in the eastern US. Water runoff shortages caused decreases in hydro-power and in available steam electric power coincident with increased air conditioning loads. However, the electric system was able to handle the situation without curtailment of power.

Some renewable energy systems such as solar, wind energy, and biomass are directly sensitive to climate change. Central solar thermal electric systems and many geothermal systems are similar to steam electric plants in terms of cooling requirements, although there are differences in sensitivity due to their steam temperature. Biomass energy systems are similar to agriculture and forestry in sensitivity to climate change, except for differences in management practices. Intensively managed biomass systems may be able adapt to changes subject to availability of water resources.

### *1.4 Developing countries*

Developing countries tend to have different mixes of energy technologies and are often at different stages of development of their energy-using and supply systems than developed countries. Since drought conditions tend to diminish both hydro and traditional biomass sources simultaneously, countries with a relatively high dependence on those sources are more vulnerable. Africa, non-OECD Asia and Latin America are particularly high in dependence on biomass energy, ranging from as high as 100% in one country and above 90% in a number of African and Asian countries. Latin America and non-OECD Asia also are particularly high in dependence on hydro-power. Semi-arid countries usually are most vulnerable to natural fluctuations in precipitation, even without global climate change. Tropical developing countries represent a potentially large source of increased demand for electricity for air-conditioning. Demand may grow both with improved economic conditions and with higher temperatures.

### *1.5 Regional studies*

Since the first IPCC assessment of the impact of climate change on the energy sector, several regional or utility-specific studies have been published. These studies examine changes in energy supply and demand simultaneously for the specific regional energy scheme. The methods and magnitude of impact vary, but together these studies serve to illustrate the importance of specific regional impact studies, especially for long-range plans which may already be in progress. Regional studies, the results of which are discussed below, are from the US, Finland, New Zealand, Great Britain, Japan and the former USSR.

Climate sensitivity in the energy sector and in energy use varies greatly from region to region. Hydro-electric power is sensitive to temperature and precipitation; in some regions, because of evaporative losses, even increased precipitation does not lead to increased streamflow.

Thermal plants are moderately sensitive to increases in air and water temperature, but water supply problems can lead to power interruption. Areas in which seasonal demand is highest in the winter may have significantly lowered total annual energy needs. In contrast, regions with high or increasing air-conditioning demand may have a significant increase in summer daily peaking, with substantial costs for additional peaking capacity, but only moderate additional energy costs.

## 2 Human settlement

Among the most significant of all the potential impacts of climate change are the possible effects on human settlements, a broad term meant to encompass a) housing or shelter, b) the surrounding village, neighbourhood or relevant social unit in which individuals live, c) the supporting physical infrastructure (eg water services, communication links, transportation) and d) social and cultural services (eg health services, education, police protection, recreational services, parks and so on).

The Missouri-Iowa-Nebraska-Kansas (USDOE 1991) study sponsored by the US Department of Energy uses a new and sophisticated methodology. It incorporates historical analogies from a period in which the weather was close to projected changes in climate, analysis of contemporary systems such as hydrological regimes and the networks that comprise the economy of the MINK area, and impositions of expected climate change both on the present natural and economic situation and on what the area will be like in 2030. Although the study is thorough throughout, its strength is in a study of the interconnections and relative importance of various parts of the economy on a small scale, using the US Forest Service's IMPLAN input-output model. This allows for a very complex understanding of the impacts that changes in sectors sensitive to climate would have on the larger economy of this highly developed region.

The projected economic impact of climate change (corresponding to an increase of 100 parts per million in $CO_2$, or a 0.65–0.9°C rise by 2030) on this agriculturally oriented part of the United States, according to the authors of this study, would be negligible except in a worst-case scenario. They conclude that agriculture would be negatively affected, but also that adjustments for on-farm adaptations and $CO_2$ enrichment of crops drop the impact below the level required to affect significantly the economy as a whole. The relative importance of manufacturing—even in this relatively specialised agricultural area—would, in effect, cushion the economy at large from possible damage. It is worth noting, however, that the temperature rise used in this analysis is below that which the IPCC Working Group I is predicting for the earth as a whole (1°C), and that all models are predicting greater warming in the interior of continents and in decades subsequent to the 2030s.

It is likely that consequential impacts of climate change can be more reliably projected on developing societies than on highly industrialised nations; there is abundant evidence that the former are already tackling formidable problems caused by climatic variability and human actions. Tropical cyclones such as the one that ravaged Bangladesh in May 1991, the recent flood in south China that left over a million homeless, and the drought-induced famine that has plagued Sudano-Sahelian Africa over the past decade (Oguntoyinbo 1991) are all manifestations of the extraordinary present vulnerability of the populations of developing countries to extreme climatic events.

The economic and social viability of such island nations as Tuvalu, Tokelau, Kiribati, the Marshall Islands and the Maldives could be imperilled by a rise in the mid range of current sea-level rise projections (Roy and Connell 1991). A rise of one metre (at the upper range of sea-level rise projections for 2100) could also displace 20–25 million people in Bangladesh (Asaduzzaman 1991) and flood delta regions in China, Egypt and India (Tickell 1989). Sea-level rise appears to be the most dangerous potential effect of global climate change on human settlement.

The study of Mexico (Liverman 1991) and the discussion of Brazil in the executive summary of the five-country UN Environment program study (Parry 1991) both emphasise that *vulnerability* to future climate change can in part be extrapolated from contemporary ecological and social reactions to climatic *variability*.

In Mexico, intense local conflicts over water rights between different types of farmers, and also with urban-dwellers, combined with large regional losses of crops to drought, illustrate the vulnerability of Mexico to changes in precipitation. Disasters can also point out this vulnerability; in Brazil, intense rainfall in Rio de Janeiro in February 1988 caused 300 deaths and $1000 million in economic losses. A very high (evidently too high) density of population and economic activity was largely responsible in this case.

In Northeast Brazil, where losses from drought are associated with the problem of poverty, a study found that 'social and economic consequences of droughts are explained by local factors such as social organisation, education and technological level as much as by weather variation' (Parry 1991 p.9). Thus, as shown in infant mortality statistics, government action in the form of public works projects may be able to offset the malnutrition caused by drought for the first few years, but as the drought continues and deepens, children die more frequently. The study concludes that more frequent extreme drought would greatly increase the impact on the rural poor (Parry 1991). Drought is also not necessarily wholly derived from factors external to the area in question. In Northeast Brazil, for example, it is in part attributable to extensive deforestation (Parry 1991).

The Brazilian and Mexican studies found that human activity both reveals and occasionally even causes vulnerability to climate variation, which can be indicative of vulnerability to climate change. Vulnerability, socioeconomic or biophysical, can indicate areas or populations where ameliorative or preventive action can be of use now as well as in possible future climates, especially where both the people and the place they live in are vulnerable to climate change.

Various studies have highlighted the potential significance of changes in the El Niño/Southern Oscillation phenomenon (ENSO) that might accompany global warming. It is estimated that the El Niño of 1982–83 caused losses of $US3 billion in the Southeast Pacific owing to disruptions in agriculture, destruction of infrastructure, and declines in fisheries production (Sotelo 1991). In Vietnam, highly productive fisheries (at the edge of upwelling and downwelling regions) have shifted during El Niño events and, as a result, overall production has declined sharply (Parry 1991). ENSO amplifies climate variability, imposes a specific temporal pattern to drought and heavy rainfall periods, and allows some predictability of these variations in Southeast Asia. If this variability is enhanced under a changed climate, then sustainable development could be made much more difficult (Nicholls 1991). Changes in atmospheric circulation that may occur under conditions of global warming could alter, by changing the connections between low and middle latitudes, the impacts of ENSO, even if the phenomenon itself remains unchanged (Nicholls 1991). At this point, however, the direction and potential magnitude of changes in ENSO under conditions of climate change is uncertain, so it is impossible to make projections of likely impacts of changes in ENSO.

Drought has a differential impact on farmers, depending on their economic and social circumstances. In Mexico, it has had a different impact on different segments and sociopolitical types of farmers. Ninety per cent of losses from natural hazards are from drought in Mexico; *Ejidos* or communally held farms, however, have consistently suffered more losses (to a maximum of twice as much in 1970) from drought than privately owned farms. This is partly explainable by the 'biophysical marginality' of these lands, but also by a lack of access to irrigation, credit and other resources. Liverman (1991) goes on to conclude that land reform and level of agricultural modernisation affect the degree of vulnerability to climate variation. These factors would also potentially affect vulnerability to global warming.

Climate change could alter the in-country urban to rural population balance. Parry (1991) states that reductions in rubber production (extrapolated from the GISS $2xCO_2$ climate scenario) in Malaysia could increase the current tendency of rubber smallholders to sell out to larger estates and move to cities. A similar urban exodus was caused in Bangladesh by massive floods from 1974–81; fully 1% of the population shifted to the cities as a result of those disasters (Asaduzzaman 1991). Sea-level rise and continued subsidence of the delta is expected to increase flooding in Bangladesh, so this type of shift can be expected to continue.

Sea-level rise along with flooding and drought may be the source of a potential *international* environmental refugee problem, with many persons fleeing their homelands to other countries. Such a refugee problem has become acute in the Horn of Africa because of a combination of drought, famine and civil war and it is likely that sea-level rise will become a force for inter-country movement. New Zealand is already considering the possibility of taking in refugees from South Pacific island populations who may face the loss of their homelands (New Zealand 1990).

Along with the prospect of a new immigration, New Zealand has also identified a potentially severe cultural impact resulting from possible displacement of the Maori. The Maori do not recognise themselves as separate from their land, and many live in low-lying areas prone to floods and possibly vulnerable to sea-level rise.

## 3 Industry and transport

Recent impact studies covering transportation only involve developed countries such as Canada, New Zealand and the US. It should be noted that the impact of transportation on climate change is very great (UK 1991) and that policies implemented to alter climate change may change the world transportation network a great deal.

Generally higher temperatures would mean lower maintenance costs, especially with a reduction in freeze-thaw cycles and if climate change produces less snow (Parry and Read 1988). The annual costs of winter maintenance in the UK is now about £120 million (Perry and Symons 1991), but new technologies in ice detection and in forecasting minimum road temperature could decrease these costs. Salt could be reduced by 20%, resulting in savings in direct costs as well as from reduced damage to cars, trucks, and road infrastructure. Savings to the Great Lakes region are estimated at $4.5 million annually in snow and ice control costs and $700 000 a year in decreased frost damage to roads and bridges (Jones and Frith 1989).

A decline in weather-related accidents could be expected, although the relationship of accidents to weather is not linear. Of fatal accidents in New Zealand, 3.8 % can be attributed to weather (Steiner 1990), and in the UK, £300 million (out of five billion) of damage from road accidents could be attributed to weather (Palutikof 1991, 1990). The severity and frequency of accidents is measurably sensitive to weather, and changes in climate could possibly change human and economic losses.

In the Great Lakes system and on inland waterways in the UK, lower water levels from increased evaporation would lead to lower lake levels and a decreased cargo capacity, 13 % in the Great Lakes under the GISS scenario (McBoyle and Wall, in press). Arctic shipping, however, would have a significantly lengthened season.

Water-based industries will receive the most direct impacts from climate change. Industries needing water, such as paper making, food processing, and power generation could be affected by changes in supplies in a hydrologically different world. The US MINK study reports that industrial production would be reduced by 'a few billion dollars—maybe 2 or 3...' (VI, p. 26, USDOE 1991). This reduction would not however have a significant impact on industry or the economy as whole unless agricultural production dropped by more than 10%.

Since a large proportion of industry is established near coasts and waterways for easier access to transportation, cooling, energy, and waste removal, it could be endangered by sea-level rise. In the UK, 40% of the industrial sector is located in coastal and estuarine areas. The value of property protected by the Thames barrier alone is estimated at £10–20 billion (UK 1991). The threat is common to both industrialised and developing countries alike as civilisation has historically developed near coastal areas and waterways. Oguntoyinbo (1991) warns that the transportation, housing and industrial infrastructures of many West and Central African coastal cities could be at risk from sea-level rise.

A study of climate's present and future influence on the economy of Europe enumerates many possible implications of changes in climate and ultra-violet radiation for the construction and insurance industries. Design parameters for construction are currently based on historical climate conditions, particularly the extreme values of temperatures, wind speed, groundwater levels and rainfall. Some of these values will change with climate change; others are expected to, although the magnitude and direction of change are still in doubt. The study recommends that future design take account of possible changes in climate from greenhouse gas forcing. Another parameter that will change in the future is the future level of ultraviolet radiation (from destruction of stratospheric ozone—see Section 6). Synthetic materials already sensitive to UV-B such as plastic polymers (used in paints, window frames, and roof coverings) could degrade more quickly with enhanced UV-B.

In the insurance industry, risk estimates in areas such as damage from storms have been based on historic loss statistics. This may not be as viable an approach in the future, especially given that damage from extreme events tends to rise rapidly with small increases in, for instance, maximum wind speed. Changing climatic baselines could alter the probability of such high-loss events; the authors of the study suspect in fact that human activity already has.

## 4 Health

Global warming may indirectly affect morbidity, mortality and human health. For example, in temperate regions, mortality for pneumonia and bronchitis, and cardiovascular, cerebrovascular and heart diseases achieve a winter maximum and a summer minimum (Momiyama and Katayama 1972). Mortality of infectious diseases other than pneumonia and bronchitis is also seasonal, but increases both in winter and in summer (Ando 1991). As a result of global warming, the mortality rates may be reduced in winter and increased in summer (Iriki and Tanaka 1987).

Global warming should affect human hazards such as parasites and pathogens, as well as those deriving from chemical pollutants. It could also affect human health by producing changes in air and water quality (Pearman 1988; Ewan 1990; Smith 1991; Breslav et al. 1991). Sea-level rise and acceleration of drought conditions could produce large numbers of environmental refugees with concomitant health problems.

Health problems may increase in cities as the already sizeable 'heat island' effect, which has been proven to raise temperatures in cities, is added to raised temperatures associated with global warming (Sugandhy 1991).

Estimating the pathophysiological mechanisms of the adverse effects of heat stress on human health requires experimental studies using model animals. Heat stress in laboratory animals significantly induces lipid peroxidation in the liver (Ando 1991). Heat stress has significant physiological and epidemiological impacts, and increased heat stress from climate change could lead to increased mortality in certain countries. The degree of acclimatisation (adaptation) to rising temperatures is expected to be extremely important in determining the extent of expected increases in mortality (Kalkstein 1989).

Multi-year observations of the runoff and chemistry of 168 Russian rivers show that a runoff reduction of

30–50 mm (that would result from a temperature increase of 1.2°C) would increase river pollution. The concentrations of a number of pollutants in river water would exceed national water quality standards in a territory of over 1.2 million $km^2$. This would render the water unsuitable, without pre-treatment, as a potable water supply for human settlement (Breslav, Boltneva, and Nazarov 1991). The solubility of many pollutants in water is also expected to rise with increased temperature.

Global warming may modify the incidence and range of vector-borne diseases. If global warming changes rainfall and temperature patterns, the seasonal and geographical abundance of the major vector species could change. Since some vector-borne diseases are well known to show apparent seasonal changes, the diseases seem to be very sensitive to climate, and thus could be sensitive to global warming. Diseases such as malaria, Chagas disease (trypanosomiasis) schistosomiasis, lymphatic filariasis, onchocerciasis (river blindness) leishmaniases, dengue fever, yellow fever, Japanese encephalitis (WHO 1990), and Australian encephalitis (Ewan 1990) could potentially increase or be reintroduced in many countries as a consequence of global warming.

More specifically, a recent New Zealand study concludes that global warming could increase the possibility that many medically important pest species currently not present in New Zealand could become established there. One species, the dengue-bearing *Aedes albopictus*, has recently arrived in Fiji, and is poised to enter New Zealand. The islands of Tokelau are also at risk from the pest, with sea-level rise potentially creating more brackish water in which it could breed. *Aedes aegypti*, which also carries dengue and dengue haemorrhagic fever, has only been kept out of New Zealand by a few degrees of cold, and warming could thus easily change this situation. The mosquito that is most important medically in New Zealand (*Culex quinquefasciatus*) could also expand its range with increased temperature (New Zealand 1990).

## 5 Ultraviolet radiation and health

One supposition about impacts of UV-B on health that has been confirmed is that UV-B induces immunosuppression in humans. This was found to affect humans regardless of pigmentation, and could lead to greater incidence or severity of infectious diseases including (but not limited to) the viruses involved in herpes, papilloma, and acquired immunodeficiency disease. Previous speculation had been that peoples with dark pigmentation might not be at risk, but this new discovery indicates that all the world's population is at risk from UV-B induced immunosuppression (UNEP 1991).

Although UV had been associated with damage to the lens, retina and cornea, including the formation of two kinds of cataracts, two new conditions have been related to UV exposure. These are presbyopia, often called age-related near-sightedness, and deformations of the anterior lens capsule (UNEP 1991).

Exposure to UV-B is known to be associated with increased skin cancers ranging from basal cell and squamous cell carcinomas (BCC and SCC) to more dangerous melanomas. Research within the last two years has confirmed this further, but has slightly reduced projections of incidence from a decrease in ozone. A change in the radiation amplification factor for non-melanoma skin cancers has reduced projections of incidence increase from 2.7% (BCC) and 4.6% (SCC) per 1% ozone reduction to 2.0% and 3.5%, respectively (de Gruijl et al. to be published). This has been supported by Moan (1991) in estimations of SCC and BCC incidence in the Norwegian population. The most up-to-date estimate of skin cancers caused by decreased ozone (a 10% decrease lasting two to four decades) after three to four decades is 300 000 additional cases of non-melanoma cancer and 4500 additional cases of melanoma (UNEP 1991). Recent reports also indicate that salivary gland cancer (which is a non-skin cancer) may be associated with UV-B exposure (Spitz 1988, 1990).

## 6 Air quality

Global warming would accelerate the photochemical reaction rates among chemical pollutants in the atmosphere, increasing oxidants in many urban areas (Hatakeyama et al. 1991). In the summer, high concentrations of oxidants are already observed in the major metropolitan area. Predicted global warming may increase the ozone concentration in this and other metropolitan areas and increase the extent of this pollution as well (Ando 1991).

Climate changes could be a major factor on long-term trends in acid deposition, air pollution in urban areas, and levels of radon emitted from soils (Nazarov 1991).

The main pollutants derived from photochemical reactions are ozone and peroxyacetyl nitrates. There is a great deal of evidence associating these photochemical oxidants with acute effects on human health. Gas-particle partitioning coefficients and gas-phase reaction rates with $RO_2$, OH, and $O_3$ are temperature dependent (Pankow and Bidleman 1991; Atkinson 1990).

Biogenic emission of NO and VOC such as isoprene would be increased with the increase of air temperature (Williams et al. 1987; Junti and Atkinson 1990; De Leeun et al. 1990). An increase of 5°C could lead to an almost

50% increase in the total source strength of $CH_4$ (Hameed and Cess 1983). A 2°C increase in temperature could be associated with a 10–30% increase in tropospheric $H_2O$ levels, implying a few per cent increase in OH and other $HO_x$ family members(Thompson et al. 1989).

The RTM-III model was run using an increased temperature scenario (a uniform 4°C with an increase in water vapour concentration assuming constant specific humidity). Peak daily ozone concentrations in the warmer model increased by 3% to 20% (mean increase of 9%). In the midwestern and southeastern United States, the changes in ozone ranged from -2.4% to 8.0%, with a mean value of 3.4% (Morris et al. 1989). The model suggests that approximately three times as many people in central California and 60% more people in the midwestern/ southeastern modelling domain would be exposed to ozone concentrations in excess of US air quality standards as a result of the 4°C increase.

All the other model calculations lead to similar tendencies of increase in urban oxidant formation with the increase in air temperature (Dodge 1989; Penner et al. 1989). A decrease in column ozone of 20% would lead to an OH increase of roughly 15% over continental areas (Thompson et al. 1989; Liu and Trainer 1988). The concentrations of $HNO_3$, PAN and $H_2O_2$ would be increased for reduction in overhead ozone (Frank et al. 1991).

However, recent information indicates that much of the warming would occur at night. Generally that will not affect photochemical oxidation because of the absence of sunlight during that period. Moreover, warming may cause both increased cloudiness and more instances of rainfall: both factors would tend to reduce oxidation and encourage cleansing of the atmosphere. Thus, the net effect on the ambient air quality due to climate change is uncertain in both direction and magnitude.

## 7 Effects of ultraviolet-B radiation

### 7.1 *General results*

The effects of UV-B radiation on approximately 300 species and varieties of plants have now been studied. Of those studied, nearly one-half showed physiological damage and/or growth in response to UV-B radiation (Teramura and Sullivan 1991). A summary of studies conducted on soybean shows that 26 of 41 cultivars tested were sensitive (growth reductions exceeding 5%) to UV-B radiation in field or greenhouse studies (Teramura and Sullivan 1991).

It is now widely known that plants grown in growth chambers appear to be more sensitive to a given UV dose than field-grown plants. The basis for this difference in sensitivity comes from the fact that in artificial environments only a single factor is manipulated; all other factors are either kept constant or are optimised for growth. Such single factor stresses are rarely experienced by plants outdoors (Teramura and Sullivan 1991).

A general response to drought, nutrient limitations and high irradiance (visible and UV) is the accumulation of flavonoids in epidermal tissues. These compounds absorb strongly in the UV-A and UV-B spectra and their accumulation in the epidermis has been shown to reduce epidermal transmittance of UV. It has now been established that the synthesis of several of the key enzymes in the flavonoid biosynthetic pathway are induced by UV-B (Teramura and Sullivan 1991).

A study of the comparative and cumulative effects of UV-B on wheat, rice and soybean seed yields and total biomass revealed that UV-B in combination with $CO_2$ eliminated the latter's enrichment effects in either seed yield or biomass for wheat and rice, but yields and biomass increased or were maintained in soybeans (Teramura 1990). Solar radiation bleaches cellular pigments of freshwater and marine phytoplankton and also impairs motility and photomovement of the plankton. These effects seem to be caused by solar UV-B (Eggersdorfer and Hader 1991; Hader and Hader 1989a, b; 1990a, b; Hader and Worrest 1991). In the paraflagellar body, UV-B radiation has been found to affect the proteins that carry the photoreceptor chromophores, flavins, and pterins. In addition, the chromophores are affected by the radiation.

Recent measurements in Antarctic waters have indicated a reduction in photosynthesis rates of 6% to 12% for total water column productivity at times and locations when increased UV-B was experienced (Smith et al. 1992). The photosynthetic pigments are affected and consequently the production of energy and reduction equivalents decreases, which in turn hampers $CO_2$ incorporation in organic material (Hader and Worrest 1991). UV-B has been found to have an effect as far down in the oceans as 37 metres (UNEP 1991).

Marine invertebrates differ greatly in their sensitivity to UV-B radiation. Small crustacean and larval shrimp are particularly sensitive to UV-B radiation. There is evidence that a decrease in column ozone abundance could diminish the near-surface season of invertebrate zooplankton populations. For some zooplankton, the time spent at or near the surface is critical for food gathering and breeding (Hader and Worrest 1991).

The marine phytoplankton communities represent by far the largest ecosystem on earth. Therefore, even a small percentage decrease in population would result in enormous losses in the biomass productivity of the ocean, which would have dramatic effects both for the intricate ecosystem itself and for humans, who depend on this system in many ways (Hader et al. 1989).

There may be considerable differences in sensitivity to UV-B radiation between phytoplankton species (Kelly 1986; U.S. EPA 1987). Increased UV may lead to a pronounced shift in the species composition of the primary producers as well as of the consumers. Indirect effects may also occur in the form of altered patterns of predation, competition, diversity, and trophic dynamics if species resistant to UV-B were to replace sensitive species (Hader 1991).

Any decrease in the phytoplankton populations will decrease the sink capacity for atmospheric $CO_2$. A population decrease of 10% would equal the net $CO_2$ increase due to fossil fuel burning. This is not yet accounted for by the current climate change models (Hader 1991).

### 7.2 *Determination of sensitivities*

Given a 16% ozone decrease over temperate pelagic waters, UV-B radiation levels at a depth of 1 meter would reach a lethal (50% mortality) cumulative radiation dose in fewer than 5 summer days for about half the zooplankton species examined. Perhaps even more important, the threshold levels of UV-B exposure would occur earlier in the year than has been the case, a time when these species are normally found near the surface (Damkaer et al. 1981; Dey et al. 1988).

On the North American Pacific coastal shelf, anchovy larvae are restricted to the upper 0.5 metres, and therefore a 16% ozone reduction could lead to large increases in larval mortality (Hunter et al. 1982). Experiments have shown that larvae 2, 4, and 12 days old would have 50, 82, and 100% mortality (Hader and Worrest 1991).

For the sensitive soybean cultivar, a 25% ozone reduction reduced overall yield by 19–25% during four of the six years. In contrast, yield increased from 5 to 22% in five of the six years for the UV-B resistant cultivar (Teramura and Sullivan 1991). After three years of supplemental irradiation of UV-B simulated those that would be anticipated with stratospheric ozone reductions of 16% and 25%, plant biomass was reduced by 12% to 20% at the highest simulated ozone depletion (Sullivan and Teramura 1991).

### 7.3 *Study tasks for the near future in aquatic ecosystems*

The molecular mechanisms for UV-B damage need to be determined for many zoo- and phytoplankton species, especially those that are ecologically important. The question remains whether the gene pool within plankton species is variable enough to adapt during the relatively gradual changes anticipated for UV-B radiation exposure.

The combined effects of direct (larval mortality) and indirect (food web) losses cannot as yet be predicted, nor have assessments been made of adaptive strategies or genetic selections that could minimise population or ecosystem effects.

The problems of extrapolating laboratory findings to the open sea, and the nearly complete absence of data of the long-term effects and ecosystem responses make it difficult to assess the possible long-term impacts of increased UV radiation.

The interaction between UV-B dose and microclimate variation needs further evaluation. Studies extending over several growing seasons and an evaluation of the metabolic or energetic costs of producing and maintaining high flavonoid concentration will be necessary to determine the effects of increasing solar UV-B radiation on overall tree productivity.

UV-tolerant plants do possess various types of UV-protective and repair processes, which suggests that increased UV resistance in crops might be achieved via breeding programs. But we currently lack information on the genetic basis and heritability of UV resistance to estimate the feasibility of such crop improvement programs.

We know very little about potential indirect effects of UV-B radiation changes on competitive ability or resistance to insects and pathogens.

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