CCP4 SM

Mediterranean Region Supplementary Material

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SMCCP4.1 Detection and attribution of climate change impacts in the Mediterranean Basin

Table SMCCP4.1 | References supporting Figure CCP4.5 (Attribution of observed impacts of climate change in the Mediterranean region).

Impact	Supporting references
Thermal discomfort	Heatwaves are increasing due to climate change in the Mediterranean, and are amplified in cities due to urbanization practices, ultimately increasing mortality and morbidity rates, as well as energy consumption (*high agreement, robust evidence* in the north, *medium evidence* in the south) (Chapters 9 and 13; WGI Chapters 10 and 12; Kuglitsch et al., 2010; Salvati et al., 2017; Zinzi and Carnielo, 2017; Pyrgou and Santamouris, 2018; Salameh et al., 2019; Maggiotto et al., 2021).
Pluvial and river flooding	There is a mixed signal of increasing and decreasing flood trends in the Mediterranean (Gaume et al., 2016; Blöschl et al., 2017; Gudmundsson et al., 2017; Kundzewicz et al., 2017; Siam and Eltahir, 2017), and there is *low confidence* in attribution to climate change due to the major impacts of human interventions, such as land use change, groundwater exploitation, urbanization and non-optimal flood risk management (Working Group I (WGI) Chapters 11 and 12 for extreme precipitation changes; Llasat et al., 2013; Mediero et al., 2014; Ziv et al., 2014; Baahmed et al., 2015; Polemio and Lonigro, 2015; Gaume et al., 2016; Llasat et al., 2016; Paprotny et al., 2018; Ribes et al., 2019; Tramblay et al., 2019; Vicente-Serrano et al., 2019; Argaman et al., 2020).
Water availability and quality	There is *high confidence* in detection and attribution of climate change impacts on water availability in the northwestern Mediterranean, and *medium confidence* in other sub-regions. There is emerging evidence on the impacts to water quality (Chapters 9, 13; WGI Chapters 8, 11; Hoerling et al., 2012; Ruffault et al., 2013; Vicente-Serrano et al., 2014; Aguilera et al., 2015; Quintana-Seguí et al., 2016; Van Vliet et al., 2016; Gosling et al., 2017; Spinoni et al., 2017; Caloiero et al., 2018; Mathbout et al., 2018; Okkan and Kirdemir, 2018; Braca et al., 2019; Grillakis, 2019).
Wildfires	There is *medium confidence* that, in Mediterranean Europe, wildfires are decreasing owing to good practices (Brotons et al., 2013; Turco et al., 2014; Turco et al., 2016), despite the increasing hazard caused by increased drought frequency and severity (WGI Chapter 11; Pausas and Fernández-Muñoz, 2012; Karali et al., 2014; Fernandes et al., 2016; Turco et al., 2017b; Ruffault et al., 2018). There is *low confidence* in any trends on wildfire for the south Mediterranean due to the lack of attribution studies, limited monitoring of direct human interventions and also limited fuel availability in the southeast Mediterranean (Meddour-Sahar, 2015; Turco et al., 2017a; Curt et al., 2020).
Coastal flooding and erosion	Chronic flooding in Venice (Box 13.1) and generally extreme Mediterranean water levels during storms increase consistently with sea level rise (Marcos et al., 2009). Flood and erosion hazards and risks have not been attributed to climate change yet, as they highly depend on coastal management strategies (WGI Chapter 13; Frihy et al., 2010). Pocket beaches in the Mediterranean might be early responders to sea level rise (Brunel and Sabatier, 2009). Some permanent flooding is observed in subsiding areas. such as the region near Thessaloniki (Greece) (Raucoules et al., 2008).
Marine ecosystems	New evidence published since AR5 (Cramer et al., 2014; Wong et al., 2014) confirms that a shift in Mediterranean marine ecosystems, characterized by biodiversity decline and invasive species, has occurred since the 1980s, with *high confidence* of a major climate change imprint superimposed with the impacts of human activities (Chapter 3; Fortibuoni et al., 2015; Stergiou et al., 2016; Corrales et al., 2017; Givan et al., 2018; Azzurro et al., 2019; Kim et al., 2019; Albano et al., 2021).
Inland ecosystems	New evidence since AR5 WGII Chapter 18 (Cramer et al. 2014) confirms that terrestrial and freshwater ecosystems are impacted by climate change in the Mediterranean, resulting in loss of habitats and biodiversity, and range shifts (e.g., birds), including through cascading impacts such as drought and wildfires (*high confidence* in northern Mediterranean, *medium confidence* in southern Mediterranean) (Chapters 9, 13; CCP1; Stefanescu et al., 2011; Peñuelas et al., 2018; Bartsch et al., 2020).
Fisheries	New evidence published since AR5 WGII Chapter 18 (Cramer et al. 2014) further confirms that climate warming has had a negative impact on exploited marine fish stocks (*high confidence*), superimposed on the impacts of human activities, such as overfishing (Sabatés et al., 2006; Lejeusne et al., 2010; Sabatés et al., 2012). The economic value of proliferating species is generally less than that of declining species (*high confidence*) (Coll et al., 2014; Tsikliras and Stergiou, 2014; Stergiou et al., 2016; Azzurro et al., 2019).
Agriculture and viticulture	Changes in seasonality are attributed to climate change and the drying trends affect agriculture negatively (low confidence in the southeast Mediterranean and medium confidence in other sub-regions) (El-Maayar and Lange, 2013; Garcia-Mozo et al., 2015; Moore and Lobell, 2015; Oteros et al., 2015; Seif-Ennasr et al., 2016; Di Lena et al., 2018).

SMCCP4.2 Projected climate risks

The following tables provide the quantitative basis and literature references for the 'burning ember' illustrations in Figure CCP4.8.

Table SMCCP4.2a | Supporting material for water availability and quality.

Risk with no/ low adaptation	Range of temperature transition	Confidence level for transition	Explanation (text and references)
Undetectable to Moderate	0.8–1.0	*high*	– Increase of the fractional area under soil drought in the northern Mediterranean by 4–14% (Grillakis, 2019). – Reduction (median) in mean annual runoff in Spain by 5%, compared to 1980–2010 (Gosling et al., 2017). – Reduction of groundwater recharge in Italy by 7—12% from 1996–2015 (Braca et al., 2019). – Reduction of reservoir inflows in Turkey by 15% from 1980–2005 (Okkan and Kirdemir, 2018). – Change of gross hydropower potential by –5% up to +20% in the northern Mediterranean and by 5–60% in the southern Mediterranean, compared to 1971–2000 (Van Vliet et al., 2016). – Reduction of cooling water discharge capacity by 5–60%, from 1971–2000 (Van Vliet et al., 2016) – The Standard Precipitation index (SPI) displays decreasing trends in the Mediterranean Basin (trends less clear in southern France). The typical characteristics of droughts (12–24 months SPI) mean that they have relevance for water management (Caloiero et al., 2018). – The SPI (driven by precipitation) and SPEI (driven by precipitation and temperature) displays remarkable drying trends in southern Europe, especially in summer and autumn over the last three decades, both in terms of frequency and intensity (Spinoni et al., 2017). – Increased severity of droughts in Spain attributed to higher evaporative demand due to rising temperatures (Vicente-Serrano et al., 2014). – Increase in drought intensity and duration as well as seasonality changes are detected in sub-regions of Mediterranean France (Ruffault et al., 2013). – The Mediterranean drying after 1970 during the winter season is partly attributed to anthropogenic climate change (Hoerling et al., 2012). – Identification of drought clusters in northwestern Mediterranean in the 1940s since the 2000s and in Eastern Mediterranean since the 1980s (Quintana-Seguí et al., 2016). – A drying trend is reported in the Eastern Mediterranean (Mathbout et al., 2018). – There is *medium* to *high confidence* that anthropogenic climate change has increased drought severity in the Mediterranean (WGI Chapters 8; 11).
Moderate to High	1.4–2.0	*high*	– *High confidence* in increase of hydrological, agricultural and ecological droughts in the Mediterranean between 1.5° and 2°C of GWL (WGI Chapter 11). – Aridity is projected to expand in the South Mediterranean (CCP3 (Cross-Chapter Paper 3)). – Reduction of streamflow (90th percentile) by 12–16% in northern Mediterranean, compared to 1971–2000 (Marx et al., 2018). – Reduction of average annual discharge in Spain by 14–37% from 1971–2000 (Marcos-Garcia et al., 2017) and by 13–14% from 2003–2013 in Italy (Pumo et al., 2016). – Reduction (median) of mean annual runoff in Spain by 20% compared to 1980–2010 (Gosling et al., 2017) and of surface runoff in Turkey by 7–20% from 1970–2000 (Bucak et al., 2017) – Reduction of low flows in France by 12% from 1980–2009 (Andrew and Sauquet, 2017) and by 15% or more over southern Europe (Roudier et al., 2016). – Reduction of inflow in Spanish dams by 15–17% from to 1992–2011 (Zabalza-Martínez et al., 2018). – Reduction of groundwater recharge in Italy by 10–18% from baseline (Masia et al., 2018; Braca et al., 2019). – Reduction of reservoir inflows in Turkey by 21% from 1980–2005 (Okkan and Kirdemir, 2018) and of reservoir maximum water level by 14–31% from 1970–2000 (Bucak et al., 2017). – Reduction of mean annual streamflow volume in Israel by 45–47% from 1996–2005 (Peleg et al., 2015). – Reduction of water availability in southwestern Mediterranean by up to 40% from to 1976–2005 (Tramblay et al., 2018). – Reduction of groundwater volume by 26–42% in a semiarid catchment in Italy compared to baseline (Guyennon et al., 2017) and of groundwater availability in Greece by 12–18% from historic levels (Koutroulis et al., 2016). – Reduction of hydropower production in Spain by 13–33% from baseline (Lobanova et al., 2016; Solaun and Cerdá, 2017) and by 10–20% on average over the entire Mediterranean (Turner et al., 2017). – Reduction of gross hydropower potential by 60% or more from 1981–2000 (Van Vliet et al., 2016; Zhang et al., 2018). – Reduction of available freshwater for cooling of thermal power plants by 6–18% from baseline in Spain and other northern Mediterranean locations (Payet-Burin et al., 2018; Tobin et al., 2018). – In France, increase of area under risk of severe drought by 14–66% (EEA, 2017; Lozano et al., 2017; Peñuelas et al., 2017; Varela et al., 2019). – Increase of the highest probability of four consecutive drought years by 20–82% compared to 1967–2016 (Lehner et al., 2017). – Reduction of annual runoff by 9–37% (Schleussner et al., 2016; Sellami et al., 2016).

Risk with no/low adaptation	Range of temperature transition	Confidence level for transition	Explanation (text and references)
High to Very High	2.7–3.2	*high*	– Warming at 2.7–3.2°C: – Reduction of hydropower production in Spain by 55% from baseline (Lobanova et al., 2016; Solaun and Cerdá, 2017). – Reduction (median) of mean annual runoff in Spain by 20% compared to 1980–2010 (Gosling et al., 2017). – Reduction (median) in groundwater water availability in Greece by 27% (Koutroulis et al., 2016). – Reduction of streamflow (90th percentile) by 35% in northern Mediterranean compared to 1971–2000 (Marx et al., 2018). – In Turkey, reduction (median) of surface runoff by 52% and reservoir maximum water level by 75–78% from 1970–2000 (Bucak et al., 2017). – Warming higher than 3.5°C: – Very likely increase of hydrological, agricultural and ecological droughts in the Mediterranean at 4°C of GWL (WGI Chapter 11) – In Italy, reduction of: (a) groundwater volume by 57% in a semiarid catchment compared to baseline (Guyennon et al., 2017); (b) groundwater recharge by 42% from baseline (Braca et al., 2019); (c) of average annual discharge by 32% from 2003–2013 (Pumo et al., 2016). – Reduction of water availability in southwestern Mediterranean by up to 55% from to 1976–2005 (Tramblay et al., 2018). – Reduction of annual runoff in Portugal by 40–70% from 1961–1990 (Mourato et al., 2015). – Reduction of annual discharge in Tunisia by 41–58% from 1970–2000 (Dakhlaoui et al., 2020). – Reduction of surface runoff in Morocco by 55–63% from 1989–2009 (Marchane et al., 2017). – Increase of the highest probability of four consecutive drought years by 220% compared to 1967–2016 (Lehner et al., 2017). – Reduction of gross hydropower potential by 20–60% in northern Mediterranean and by 40–60% or more in southern Mediterranean from 1981–2000 (Van Vliet et al., 2016). – Reduction of hydropower production in Spain by 30–55% from baseline (Lobanova et al., 2016; Solaun and Cerdá, 2017). – Reduction of cooling water discharge capacity by more than 60% from 1971–2000 (Van Vliet et al., 2016).

Table SMCCP4.2b | Supporting material for wildfires.

Risk with no/low adaptation	Range of temperature transition	Confidence level for transition	Explanation (text and references)
Undetectable to Moderate	0.8–1.5	*medium*	– Change of burnt area in northern Mediterranean by –5% to +54% (Wu et al., 2015; Turco et al., 2018). – In Italy, change of fire probability by –4.2% to +11.6%, of fire potential index by –5.5% to +11.8%, and of high flame length probability by –50% to +25% (EEA, 2017; Lozano et al., 2017; Peñuelas et al., 2017; Varela et al., 2019). – Wildfire hazard increasing due to increased drought frequency and severity (Pausas and Fernández-Muñoz, 2012; Karali et al., 2014; Fernandes et al., 2016; Turco et al., 2017b; Ruffault et al., 2018), but human interventions remain key driver of wildfire risk (Meddour-Sahar, 2015; Turco et al., 2017a; Curt et al., 2020), decrease of wildfire risk in the northern Mediterranean (Brotons et al., 2013; Turco et al., 2014; Turco et al., 2016). – Times of emergence of increased wildfire risk by the mid-21st century in the northwestern Mediterranean (Lozano et al., 2017).
Moderate to High	1.6–2.5	*medium*	– Increase of areas prone to fire risk by 53% in Corsica (Garbolino et al., 2016). – Area with 7 or more days with extreme fire weather increasing by 82–217% in southern France (EEA, 2017; Lozano et al., 2017; Peñuelas et al., 2017; Varela et al., 2019). – Increase of fire risk in Turkey by 20% on average (Satir et al., 2016). – Increase of the number of days in summer with Fire Weather Index (FWI) ≥ 15 by 20–50% in central-northern Italy and by 2–20% in southern Italy (Faggian, 2018) – Increase of burnt area in northern Mediterranean by 62–87% (Turco et al., 2018).
High to Very High	3.0–3.7	*low*	– Increase of burnt area in northern Mediterranean by 37–187% (Wu et al., 2015; Turco et al., 2018).

Table SMCCP4.2c | Supporting material for terrestrial and freshwater ecosystems.

Risk with no/ low adaptation	Range of temperature transition	Confidence level for transition	Explanation (text and references)
Undetectable to Moderate	0.7–1.2	*high*	– New evidence since AR5 WGII Chapter 18 (Cramer et al. 2014) confirms that terrestrial and freshwater ecosystems are impacted by climate change in the Mediterranean, resulting in loss of habitats and biodiversity and range shifts (e.g., birds), including through cascading impacts such as drought and wildfires (*high confidence* in northern Mediterranean, *medium confidence* in southern Mediterranean) (Chapters 4, 9 and 13 and CCP1; Stefanescu et al., 2011; Peñuelas et al., 2018; Bartsch et al., 2020).
Moderate to High	1.5–2	*medium*	– Terrestrial ecosystems negatively impacted by drought and wildfires (Guiot and Cramer, 2016; Matías et al., 2019; Sánchez-Salguero et al., 2020), and freshwater species and ecosystems (including fishes, insects, molluscs) negatively affected by reduced river flow and alteration of the water quality (Chapters 2 and 4; CCP1; see Tables SMCCP4.2a and SMCCP4.2b; Jarić et al., 2019; Lefebvre et al., 2019). – Mediterranean island endemic species especially at risk due to low possibilities to migrate (CCP1).
High to Very High	2–3	*medium*	– Terrestrial species such as land plants, insects, birds, reptiles and mammals are projected to be negatively affected, with a steep increase projected risks between 2° and 3°C of warming (CCP1; Manes et al., 2021). – Arid conditions gaining space in the Mediterranean region, with, e.g., 13–30% of Mediterranean Natura 2000 area and 15–23% of Natura 2000 sites projected to become arid above 3°C GWL (Barredo et al., 2016). – Substantial loss of habitat in freshwaters, e.g., 25% (RCP4.5) and 40% (RCP8.5) for brown trout in 2100 (Santiago et al., 2016).

Table SMCCP4.2d | Supporting material for marine ecosystems.

Risk with no/ low adaptation	Range of temperature transition	Confidence level for transition	Explanation (text and references)
Undetectable to Moderate	0.5–1	*high*	– New evidence published since AR5 WGII Chapters 5 and 18 (Cramer et al. 2014, Wong et al. 2014) confirms that a shift in Mediterranean ecosystems has been detected since the 1980s with high confidence of a climate change imprint and continued tropicalization (*high confidence*) and mass mortality events (*very high confidence*) (Chapter 3; Fortibuoni et al., 2015; Stergiou et al., 2016; Corrales et al., 2017; Givan et al., 2018; Azzurro et al., 2019; Kim et al., 2019; Albano et al., 2021). – New evidence published since (Sabatés et al., 2006; Lejeusne et al., 2010; Sabatés et al., 2012) and AR5 WGII Chapter 18 (Cramer et al. 2014) confirms that climate warming has a negative impact on marine exploited fish stocks (high confidence), superimposed on direct human impacts. The value of proliferating species is generally less than those of declining species (high confidence) (Coll et al., 2014; Tsikliras and Stergiou, 2014; Stergiou et al., 2016; Azzurro et al., 2019).
Moderate to High	1–1.5	*high*	– Observed shift in marine ecosystems projected to continue and intensify, with, e.g., loss of seagrass habitat (WGI Chapter 3), decrease of primary production and biomass in the West Mediterranean (Macias et al., 2015; Moullec et al., 2019), decreasing biodiversity of mesozooplankton (Benedetti et al., 2018), continued tropicalization (*high confidence*) (Lloret et al., 2015; Corrales et al., 2018). – Mass mortality events due to marine heatwaves (*very high confidence*) (Chapter 3) and increased risks of extinctions as climate warms projected to continue (CCP1; Ben Rais Lasram et al., 2010; Garrabou et al., 2021; Manes et al., 2021).
High to Very High	1.5–2.5	*high*	– Increased ecosystem shifts, mass mortality events and risks of extinction for endemic species between 1.5° and 2.5°C (Chapters 3, 9, 13; Garrabou et al., 2021; Manes et al., 2021). – Loss of habitats and nesting areas (e.g., for turtles) due to beach losses induced by projected sea level rise (WGI Chapter 3). – 25% of endemic marine species in the Mediterranean projected to be at high risk of extinction due to climate change (range of projections covered: from 1.5° to 3°C) (CCP1; Manes et al., 2021). – Abundance of small to medium pelagic fish is projected to decline up to 33% by 2100 (Albouy et al., 2013; Burrows et al., 2014; Stergiou et al., 2016; Raybaud et al., 2017; Albano et al., 2021).

Table SMCCP4.2e | Supporting material for food production and security.

Risk with no/low adaptation	Range of temperature transition	Confidence level for transition	Explanation (text and references)
Undetectable to Moderate	1.0–1.4	*high*	– Decrease of wheat yield by 5% in Egypt, by 0–25% in Italy, by 18.8% in Morocco (Chourghal et al., 2016; Dettori et al., 2017; Iocola et al., 2017; Brouziyne et al., 2018; Kheir et al., 2019). – Decrease of sunflower crop water productivity by 15.7% in Morocco (Chourghal et al., 2016; Dettori et al., 2017; Iocola et al., 2017; Brouziyne et al., 2018; Kheir et al., 2019). – Decrease of olive yield by 17% in Portugal, by up to 8% in Sardinia–Sicily in Italy, and by 15–18% in Spain (Fraga et al., 2020).
Moderate to High	1.5–2.1	*high*	– Decrease of wheat yield by 9% in Egypt, by 4.5–25% in Italy (Chourghal et al., 2016; Dettori et al., 2017; Iocola et al., 2017; Brouziyne et al., 2018; Kheir et al., 2019) and by 5–55% in Algeria (Bouregaa, 2019; Cammarano et al., 2019). Decrease of wheat crop water productivity in Morocco by 21.7% (Chourghal et al., 2016; Dettori et al., 2017; Iocola et al., 2017; Brouziyne et al., 2018; Kheir et al., 2019). – Decrease of maize yield by 20–29% in Italy (Chourghal et al., 2016; Dettori et al., 2017; Iocola et al., 2017; Brouziyne et al., 2018; Kheir et al., 2019) and by 3–10% in Greece (Georgopoulou et al., 2017; Iocola et al., 2017). – Decrease of barley yield by 18–25% in Algeria (Bouregaa, 2019; Cammarano et al., 2019), by up to 12% in Greece (Georgopoulou et al., 2017; Iocola et al., 2017) and by 27% on average in the entire Mediterranean (Bouregaa, 2019; Cammarano et al., 2019). – Decrease of rice yield by 6.4% in France and by 19.6% in Italy (Bregaglio et al., 2017). – Decrease of sunflower crop water productivity by 44.7% in Morocco (Chourghal et al., 2016; Dettori et al., 2017; Iocola et al., 2017; Brouziyne et al., 2018; Kheir et al., 2019). Decrease of sunflower yield by 65% in Greece (Georgopoulou et al., 2017; Iocola et al., 2017). – Decrease of olive yield by 20% in Portugal (Fraga et al., 2020), by 3–8% in Italy (Fraga et al., 2020), by 19–21% in Spain (Fraga et al., 2020) and by 10–60% in Algeria (Bouregaa, 2019; Cammarano et al., 2019). Decrease of net primary production of olive groves by 0.02–11% in Italy (Brilli et al., 2019; Fraga et al., 2020). – Decrease of potato yield by up to –45% in northern Mediterranean (Zhao et al., 2015; Georgopoulou et al., 2017). – Decrease of various vegetable yields by 4–34% in Greece (Georgopoulou et al., 2017; Iocola et al., 2017). – Decrease of tomato yield by –19–81% over the entire Mediterranean (Saadi et al., 2015). – Apples at maturity in northeastern Spain could be of inferior quality, and chilling requirements may be unsatisfied (Funes et al., 2016; Rodríguez et al., 2019). – By 2060, more than 20% of exploited fishes and invertebrates currently found in Eastern Mediterranean could become locally extinct (Jones and Cheung, 2015; Cheung et al., 2016; MedECC, 2020). High losses of clawed lobster production by the end of the century have also been projected under RCP4.5 (Boavida-Portugal et al., 2018). For much of the Mediterranean, fisheries' revenue may decrease by 15–30% by 2050 relative to 2000 under RCP8.5 (Lam et al., 2016).
High to Very High	2.3–4.0	*medium*	– Decrease of wheat yield by 5–59% in Algeria (Chourghal et al., 2016; Dettori et al., 2017; Iocola et al., 2017; Brouziyne et al., 2018; Bouregaa, 2019; Cammarano et al., 2019; Kheir et al., 2019), by 13–17% in Egypt and by more than 14% in Italy (Chourghal et al., 2016; Dettori et al., 2017; Iocola et al., 2017; Brouziyne et al., 2018; Kheir et al., 2019). – Decrease of barley yield by 22–29% in Algeria (Bouregaa, 2019; Cammarano et al., 2019). – Decrease of olive yield by 15–64% in Algeria (Bouregaa, 2019; Cammarano et al., 2019). – Change of tomato yield by –94% to +12% in Tunisia, depending on soil type and sowing date, or even non-viable crops under some combinations of soil type–sowing date (Bird et al., 2016). – In northeastern Spain, 28–72% of the years after 2070 could have winters not fulfilling chilling requirements for apple trees (Funes et al., 2016; Rodríguez et al., 2019), while chilling requirements will be severely compromised for other fruit trees in Spain (Funes et al., 2016; Rodríguez et al., 2019). – Early maturation may result in unbalanced wines through higher sugar and lower acids in the grape must after 2050 under RCP8.5 (Fraga et al., 2016; Koufos et al., 2018). Reduction in table quality vines and wine grape production in southern Europe due to a future increase in the cumulative thermal stress and dryness during the growing season (Cardell et al., 2019). – Net irrigation requirements for date palms in Tunisia under RCP8.5 are expected to increase by 34% in 2050 compared to 2018 to sustain date production (Haj-Amor et al., 2020).

Table SMCCP4.2f | Supporting material for health and well-being.

Risk with no/low adaptation	Range of temperature transition	Confidence level for transition	Explanation (text and references)
Undetectable to Moderate	0.7–1.3	*medium*	– Population exposed to high or very high heat stress risk compared to 1986–2005 is expected to increase by 53 million people in northern Mediterranean and by 82 million people in southwestern Mediterranean (Gasparrini et al., 2017; Rohat et al., 2019). – 1.3–1.6 times higher heat-related excess mortality in Italy and Spain compared to 1987–2010 (Gasparrini et al., 2017; Rohat et al., 2019). – Increase of specific cooling demand by 50–143% in office buildings at northern Mediterranean cities (Cellura et al., 2018).
Moderate to High	1.5–2.0	*high*	– Population exposed to high or very high heat stress risk compared to 1986–2005 expected to increase by 93 million people in northern Mediterranean (Gasparrini et al., 2017; Rohat et al., 2019). – In northern Mediterranean, about 13–20,000 additional attributable deaths per warm season compared to the reference (i.e., apparent temperatures at the historical levels observed during the period 1971–2001) (Kendrovski et al., 2017). – Heat-related excess mortality in Italy and Spain could increase by 2.9–3.7 times compared to 1987–2010 (Gasparrini et al., 2017; Rohat et al., 2019). – Decadal mortality risk ratio compared to the historical mortality risk could equal 3–7 in southern Mediterranean (Ahmadalipour and Moradkhani, 2018). – More than 20,000 climate-related deaths over the entire Mediterranean due to sub-optimal fruit and vegetable consumption (Springmann et al., 2016). – The predicted probability of districts with West Nile Virus infections over the entire Mediterranean could range from 0.02 to more than 0.5, compared to an average of 0.0125 in 2014 (Semenza et al., 2016). – Increase of the epidemic potential of dengue fever in southern Europe (Liu-Helmersson et al., 2019).
High to Very High	2.1–3.1	*medium*	Under warming levels of 2.1°–3.1°C: – Increase of specific cooling demand by 50–278% in office buildings at northern Mediterranean cities (Cellura et al., 2018). – Heat-related excess mortality in Italy and Spain could increase by 3.6–3.7 times compared to 1987–2010 (Gasparrini et al., 2017; Rohat et al., 2019). – Slight increase of the epidemic potential of dengue fever in southern Europe (Liu-Helmersson et al., 2019). – Supporting evidence from Chapter 13 (Figures 13.30; SM13.10). – Under warming levels exceeding 3.7°C: – Decadal mortality risk ratio compared to the historical mortality risk could equal 8–20 in southern Mediterranean (Ahmadalipour and Moradkhani, 2018). – In northern Mediterranean, about 50,000 additional attributable deaths per warm season compared to the reference (i.e., apparent temperatures at the historical levels observed during the period 1971–2001) (Kendrovski et al., 2017). – Heat-related excess mortality in Italy and Spain could increase by 6.3–6.8 times compared to 1987–2010 (Gasparrini et al., 2017; Rohat et al., 2019). – Increase of the epidemic potential of dengue fever in southern Europe (Liu-Helmersson et al., 2019). – Increase of specific cooling demand by 134–375% in office buildings at northern Mediterranean cities (Cellura et al., 2018). – Supporting evidence from Chapter 13 (Figures 13.30; SM13.10).

Table SMCCP4.2g | Supporting material for coastal risks.

Risk with no/low adaptation	Range of temperature transition	Confidence level for transition	Explanation (text and references)
Undetectable to Moderate	0.7–1.5	*medium*	– Chronic flooding in Venice (Box 13.1). – Mediterranean extreme water levels during storms increase consistently with sea level rise (Marcos et al., 2009). – Flood and erosion hazards and risks not attributed yet, highly depend on coastal management strategies (WGI Chapter 13; Frihy et al., 2010). – Pocket beaches in the Mediterranean might be early responders to sea level rise (Brunel and Sabatier, 2009). – Some permanent flooding is observed in subsiding areas such as around Thessaloniki (Greece) (Raucoules et al., 2008). – Times of emergence of climate induced erosion after 2050 in Mediterranean beaches (Le Cozannet et al., 2016).
Moderate to High	1.5–2.0	*high*	– Multi-criteria coastal risk analysis at the scale of the Mediterranean shows potential for high risks all around the basin, with more marked potential for high risk in the southeastern Mediterranean (Satta et al., 2017). – Chronic flooding taking place at high-tide is a significant concern in Venice (Box 13.1). The MOSE barrier will prevent such flooding, but the closure of the barrier is projected to reach 2 months yr^{-1} with 50 cm of sea level rise, and adversely impact ship traffic and lagoon water exchange (Box 13.1). Chronic flooding also projected to affect other low-lying areas in the Mediterranean, such as the Ebro Delta (Sayol and Marcos, 2018), but a full picture of the problem is still missing at the scale of the Mediterranean. – Extreme water levels will change in response to two contrasting impacts of climate change in the Mediterranean: reduced storminess and increased or accelerating mean sea level rise due to climate change, with the latter dominating over the former by the mid-21st century (WGI Chapters 9, Fox-Kemper et al., 2021, and 12, Ranasinghe et al., 2021; Lionello et al., 2017), possibly becoming the main driver of extreme changes, e.g., in the northwestern Mediterranean by 2050 (Le Cozannet et al., 2015; Sayol and Marcos, 2018).
High to Very High	2.0–2.8	*high*	– Hazards (e.g., extreme water levels amplification factors and allowances) and risks (e.g., economic average annual losses) projected to increase more quickly in the Mediterranean than in other regions of the world by 2050 (Hallegatte et al., 2013; SROCC Chapter 3, Oppenheimer et al. 2019), when GWL exceed 1.6° to 2.4°C (best estimate; WGI SPM, IPCC 2021). – Shoreline retreat caused by permanent flooding is projected to become widespread in the Mediterranean for RCP8.5 by the mid-century, or for RCP4.5 during the second half of the century, and further aggravated for higher levels of climate forcing (Snoussi et al., 2008; Le Cozannet et al., 2016; Antonioli et al., 2017; Anzidei et al., 2017; Ciro Aucelli et al., 2017; Enríquez et al., 2017; Jiménez et al., 2017; Antonioli et al., 2020). Storm surge superimposed with a rise of 0.5 m in mean sea level could result in the loss of up to 90% of pocket beaches in the Aegean archipelago, at least temporarily (Monioudi et al., 2017). Sediment inputs from major rivers limited by upstream dams, reducing potential compensation of erosion by sediments (Besset et al., 2017). – Overtopping and other coastal risks induced by the combination of sea level rise, storms and waves is projected to become significant for Mediterranean ports and related activities above 50 cm of sea level rise with respect to 1986–2005, especially in the southwestern Mediterranean (Sánchez-Arcilla et al., 2016; Sierra et al., 2016; Izaguirre et al., 2021). Wave agitation in ports increases due to sea level rise despite projected decreasing offshore wave heights, reducing operability times in ports, with shallower ports being projected to be more severely affected (Sierra et al., 2017). – Groundwater salinisation projected to increase with sea level rise depending on the geological context and the processes through which aquifers are exploited and recharged. Sea level rise is not the only process causing salinisation, but is projected to add another constraint to groundwater management and to sectors such as agriculture in a number of Mediterranean coastal floodplains and deltas, e.g., in some governorates of the Nile Delta for 1 m of sea level rise by 2100 (Mabrouk et al., 2018; Mastrocicco and Colombani, 2021; Pisinaras et al., 2021).

Table SMCCP4.2h | Supporting material for committed impacts of sea level rise to cultural heritage, infrastructures and communities.

Risk with no/ low adaptation	Range of temperature transition	Confidence level for transition	Explanation (text and references)
Undetectable to Moderate	0.5–1.2	*low*	– Mediterranean sea levels are controlled by sea level changes in the Atlantic through Gibraltar Strait at multi-decadal timescales (Calafat et al., 2012), Mediterranean sea level projections are close to global trends (Thiéblemont et al., 2019) (see SMCCP4.4). – Pre-industrial temperatures resulted in stable sea level (AR5 WGI Chapter 13, Masson-Delmotte et al. 2013), whereas now recent greenhouse gas emissions have committed 0.7 to 1.1 m of sea level rise by 2300 (WGI Chapter 9) (Nauels et al., 2019). – Compared to other regions, the Mediterranean region is characterised by a very high number of cultural heritage sites exposed to sea level rises, some of which have been preserved for more than 2000 years (Marzeion and Levermann, 2014). – To date, 37 Mediterranean UNESCO World Heritage sites are at risk from flooding, and 42 at risk of erosion (Reimann et al., 2018). This includes Venice, where high-tide flooding has increased consistently with relative sea level changes (Box 13.1).
Moderate to High	1.2–1.5	*medium*	– Sea level is projected to rise between 0.3 to 3.1 m by 2300 for SSP1–2.6 (*low confidence*) (WGI Chapter 9). – Sea level committed to rise by 2 to 3 m after 2,000 years, and by 6 to 7 m after 10,000 years for 1.5°C of GWL, but these long term projections incorporate processes in which there is *low confidence* (WGI Chapter 9). – The number of UNESCO World Heritage sites exposed to flooding (erosion) increases from 37 to 40 (from 42 to 46) for a sea level rise of 1.2 m ('high-end scenario' based on Kopp et al., (2014) in Reimann et al. (2018)). Flood frequencies, depths and erosion rates increase significantly in each of the cultural heritage sites already affected today (Reimann et al., 2018).
High to Very High	1.5–2.0	*high*	– Sea levels are projected to rise between 0.3 to 3.1 m by 2300 for SSP1–2.6 (*low confidence*) (WGI Chapter 9). – Sea levels are committed to rise by 2 to 6 m after 2000 years, and by 8 to 13 m after 10,000 years for 2°C of GWL, but these long-term projections incorporate processes in which there is *low confidence* (WGI Chapter 9). – In at least 13 countries of the Mediterranean region, stabilisation of global warming at about 2°C leads to drowning areas, where at least 10% of the population currently live (Clark et al., 2016). The southeastern Mediterranean low-lying areas projected to be drowned are particularly densely populated (Clark et al., 2016).

SMCCP4.3 Sustainable development in the Mediterranean Basin

Table SMCCP4.3 | Indicators for the achievement of the Sustainable Development Goals (SDGs) as illustrated in Figure CCP4.9.

SDG1 No poverty: (sdg1_320pov; Poverty headcount ratio at $3.20/day (% population)
SDG2 Zero hunger: (sdg2_crlyld; Cereal yield (t/ha))
SDG3 Good health and well-being: (sdg3_uhc; Universal Health Coverage Tracer Index (0–100))
SDG4 Quality education: (sdg4_second; Lower secondary education completion rate (%))
SDG5 Gender equality: (sdg5_lfpr; Ratio of female to male labour force participation rate)
SDG6 Clean water and sanitation: (sdg6_water; Population using at least basic drinking water services (%))
SDG7 Affordable and clean energy: (sdg7_co2twh; CO_2 emissions from fuel combustion/electricity output ($MtCO_2$/TWh))
SDG8 Decent work and economic growth: (sdg9_intuse; Population using the internet (%))
SDG9 Industry, innovation and infrastructure: (sdg9_rdex; Research and development expenditure (% GDP))
SDG10 Reduced inequalities: (sdg10_adjgini; Gini Coefficient adjusted for top income (1–100))
SDG11 Sustainable cities and communities: (sdg11_pm25; Annual mean concentration of particulate matter of less than 2.5 microns of diameter (PM2.5) ($\mu g/m^3$)),
SDG12 Responsible consumption and production:
SDG13 Climate action: (sdg13_co2pc; Energy-related CO_2 emissions per capita (tCO_2/capita))
SDG14 Life below water: (sdg14_cpma; Mean area that is protected in marine sites important to biodiversity (%))
SDG15 Life on land: (sdg15_redlist; Red List Index of species survival (0–1))
SDG16 Peace, justice and strong institutions: (sdg16_homicides; Homicides (per 100,000 population))
SDG17 Partnerships for the goals: (sdg17_govex; Government Health and Education spending (% GDP))
The list of Northern Mediterranean countries (N) includes Bosnia and Herzegovina, Croatia, Cyprus, France, Greece, Italy, Malta, Monaco, Portugal and Spain. Southern Mediterranean countries (S) analysed are Algeria, Egypt, Jordan, Lebanon, Morocco, Syrian Arab Republic, Tunisia and Turkey.
Data extracted from Sachs et al. (2019). All analyses reported significantly different mean SDG indicator values between N and S regions with $p < 0.0001$ (Tukey–Kramer test).

SMCCP4.4 Mediterranean sea level projections

Mediterranean sea level projections presented in the FAQ are downscaled from those presented in AR6 WGI Chapter 9 (Fox-Kemper et al., 2021) and Technical Summary (Arias et al., 2021), following the method presented in Thiéblemont et al. (2019) (Table CCP4.SM.4). Until 2100, the Mediterranean sterodynamic sea levels are assumed to follow sterodynamic sea level changes in the Atlantic near Gibraltar. The procedure ignores intra-basin sterodynamic sea level changes, but avoids biases due to the resolution of models and the coarse representation of water exchanges through the Strait of Gibraltar (Landerer et al., 2014; Meyssignac et al., 2017; Parras-Berrocal et al., 2020). Furthermore, observational evidence indicates that multi-decadal sea level changes in the Mediterranean basin follow the Gibraltar forcing (Section 4.1; Calafat et al., 2012). By 2150, Mediterranean sterodynamic sea levels are assumed to follow the mean global thermal expansion.

Table SMCCP4.4 | Mean sea level projections in the Mediterranean relative to 1995–2014. There is *medium confidence* in the median values [likely range] shown for the five SSP scenarios. There is *low confidence* in the median values [17–83rd percentiles] shown for SSP5–8.5-L, a scenario based on a Structured-Expert Judgement or assuming marine ice-cliff instabilities (see WGI Chapter 9, Fox-Kemper et al., 2021, for details). Mediterranean projections include the mean Glacial Isostatic Adjustment in the Mediterranean, but not local vertical ground motions due to natural or anthropogenic processes such as tectonics or groundwater extractions.

	2050 (m)	2100 (m)	2150 (m)
SSP1–1.9	0.22 [0.15–0.30]	0.43 [0.31–0.61]	0.52 [0.32–0.81]
SSP1–2.6	0.22 [0.16–0.30]	0.46 [0.34–0.66]	0.62 [0.39–0.95]
SSP2–4.5	0.23 [0.17–0.31]	0.57 [0.44–0.79]	0.83 [0.57–1.23]
SSP3–7.0	0.24 [0.18–0.31]	0.69 [0.56–0.94]	1.08 [0.80–1.57]
SSP5–8.5	0.26 [0.20–0.33]	0.79 [0.64–1.06]	1.22 [0.91–1.78]
SSP5–8.5-L	0.24 [0.18–0.33]	0.87 [0.65–1.38]	1.89 [0.96–5.01]

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