CCP4

Mediterranean Region

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Executive Summary

The Mediterranean region hosts exceptional biological diversity and socio-cultural richness originating from three continents. The nature of the semi-enclosed Mediterranean Sea and the complex topography imply unique physiographic and ecological features. The region has undergone continuous change in human activities over several millennia, and now hosts more than 500 million people with a high concentration of urban settlements and industrial infrastructure close to sea level. The region is the world's leading tourist destination and one of its busiest shipping routes. Climate change strongly interacts with other environmental problems in the Mediterranean Basin, resulting from urbanisation, land use change, overfishing, pollution, biodiversity loss and degradation of land and marine ecosystems. {CCP4.1.1}

Previous Intergovernmental Panel on Climate Change (IPCC) reports have never assessed the Mediterranean region as an entity – but they have nevertheless shown that virtually all parts of it are vulnerable and face significant risks due to climate change. Identified regional key risks include increased water scarcity (notably in the south and east) and droughts (in the north), coastal risks due to flooding, erosion and saltwater intrusions, wildfire, terrestrial and marine ecosystem losses, as well as risks to food production and security, human health, well-being and cultural heritage. {CCP4.1.2}

Surface temperature in the Mediterranean region is now 1.5°C above the pre-industrial level, with a corresponding increase in high-temperature extreme events (*high confidence*[1]). Trends in precipitation are variable across the basin (*low confidence*). Droughts have become more frequent and intense, especially in the north Mediterranean (*high confidence*). The sea surface has warmed by 0.29°C–0.44°C per decade since the early 1980s with stronger trends in the eastern basin. Sea level has risen by 1.4±0.2 mm yr-1 during the 20th century (2.8±0.1 mm yr-1 over 1993–2018) (*high confidence*). Ocean acidity is increasing (*medium confidence*). {CCP4.1.3}

A growing number of observed impacts across the entire basin are now being attributed to climate change, along with major roles of other forcings of environmental change (*high confidence*). These impacts include multiple consequences of longer and/or more intensive heat waves, droughts, floods, ocean acidification and sea level rise, such as cascading impacts on marine and terrestrial ecosystems, as well as on land and sea use (agriculture, forestry, fisheries, tourism, recreation, etc.) and human health. {CCP4.1.4}

During the 21st century, climate change is projected to intensify throughout the region. Air and sea temperature and their extremes (notably heat waves) are *likely*[2] to continue to increase more than the global average (*high confidence*). The projected annual mean warming on land at the end of the century is in the range of 0.9–5.6°C compared to the last two decades of the 20th century, depending on the emission scenario (*high confidence*). Precipitation will *likely* decrease in most areas by 4–22%, depending on the emission scenario (*medium confidence*). Rainfall extremes will *likely* increase in the northern part of the region (*high confidence*). Droughts will become more prevalent in many areas (*high confidence*). {CCP4.1.3}

Mediterranean Sea level is projected to rise further during the coming decades and centuries (*high confidence*), *likely* reaching 0.15–0.33 m in 2050, and 0.3–0.6 m for shared socioeconomic pathways (SSP) 1-1.9 and 0.6–1.1 m for SSP5-8.5 in 2100 (relative to 1995–2014) (*medium confidence*). Higher values cannot be excluded (*low confidence*) and the process is irreversible at the scale of centuries to millennia (*high confidence*). Coastal flood risks will increase in low-lying areas along 37% of the Mediterranean coastline that currently hosts 42 million people. The number of people exposed to sea level rise is projected to increase up to 2050, especially in the southern and eastern Mediterranean region, and may reach up to 130% compared to present in 2100 (*medium confidence*). Coastal settlements, World Heritage sites and ecosystems are at longer-term risk from sustained sea level rise over at least the coming three centuries (*high confidence*). {CCP4.1.3; CCP4.2; CCP4.3; SMCCP4.4}

Due to its particular combination of multiple strong climate hazards and high vulnerability, the Mediterranean region is a hotspot for highly interconnected climate risks. The main economic sectors in the region (agriculture, fisheries, forestry, tourism) are highly vulnerable to climatic hazards, while socioeconomic vulnerability is also considerable. The low-lying areas are the most vulnerable areas for coastal climate-related risks (e.g., sea level rise, floods, erosion) and other consequent risks (e.g., saltwater intrusion and agriculture damage) (*high confidence*). Climate change threatens water availability, reducing river low flows and annual runoff by 5–70%, reducing hydropower capacity (*high confidence*). Yields of rain-fed crops may decrease by 64% in some locations (*high confidence*). Ocean warming and acidification will impact marine ecosystems, with uncertain consequences on fisheries (*low confidence*). Desertification will affect additional areas, notably in the south and southeast (*medium confidence*). Burnt area of forests may increase by 96–187% under 3°C, depending on fire management. Beyond 3°C, 13–30% of the Natura 2000 protected area and 15–23% of Natura 2000 sites could be lost due to climate-driven habitat change (*medium confidence*). {CCP4.2; CCP4.3}

1 In this Report, the following summary terms are used to describe the available evidence: limited, medium or robust; and for the degree of agreement: low, medium or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, e.g., *medium confidence*. For a given evidence and agreement statement, different confidence levels can be assigned, but increasing levels of evidence and degrees of agreement are correlated with increasing confidence.

2 In this Report, the following terms have been used to indicate the assessed likelihood of an outcome or a result: Virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, and exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, and extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*). This Report also uses the term '*likely* range' to indicate that the assessed likelihood of an outcome lies within the 17–83% probability range.

The adaptive capacity of ecosystems and human systems is expected to encounter hard limits due to the interacting, cumulative and cascading effects of droughts, heat waves, sea level rise, ocean warming and acidification (*high confidence*). Coastal protection can reduce risks from sea level rise in some regions, but the costs of such interventions and their consequences for coastal ecosystems are high (*medium confidence*). {CCP4.4.1} There is *low confidence* in the feasibility of adaptation options to sea level rise beyond 2100 or for large Antarctic ice melting. {CCP4.4.5}

Progress towards achievement of the United Nations Sustainable Development Goals differs strongly between Mediterranean sub-regions, with northwestern countries having stronger resilience than southern and eastern countries (*high confidence*). To equitably enhance regional adaptive capacity and sustainable development, while safeguarding the rights of the most vulnerable people, regional cooperation can be strengthened with a focus on the link between adaptation, costs and financial limitation, and climate justice (*high confidence*). Cooperative policies across various sectors, involving all user groups and considering all regional and sectorial differences may enhance sustainable resource use in the region (*high confidence*). {CCP4.4.6}

Sharing and co-production of knowledge can support climate adaptation practices and enhance sustainability in the Mediterranean region *(medium to high confidence)*. Currently incomplete knowledge of climate impacts and risks in the southern and eastern part of the basin hinders the implementation of adaptation measures, creating a need for implementable plans with enhanced and cooperative research and monitoring capacities between the north, south and southeast countries (high agreement). {CCP4.4}

CCP4.1 Climate Change in the Mediterranean Basin

CCP4.1.1 The Mediterranean Sea, Land and People

The Mediterranean Basin, known for its exceptional environmental and socio-cultural richness, comprises the semi-enclosed Mediterranean Sea and the countries and regions bordering it,[3] which belong to Europe, Asia and Africa (Figure CCP4.1). The region has a unique historical and environmental identity (Abulafia, 2011), despite undeniable variations in the environment, socioeconomic conditions and cultural traditions. The countries in the Mediterranean Basin hosted approximately 542 million people in 2020, a number which is expected to increase to 657 million by 2050 and 694 million by 2100. In 1950, only 23.7% of the Mediterranean population lived in countries of the south, this number increased to 41.2% in 2000, 46.3% in 2020, and is projected to reach 55.5% in 2050 and 64.6% in 2100 (UN DESA, 2019).

CCP4.1.2 Main Findings from Previous Assessments

All previous assessments of climate change for the Mediterranean Basin and its sub-regions indicate ongoing warming of the atmosphere and the sea, as well as projected warming and changes in rainfall (Stocker et al., 2013; Cherif et al., 2020). The projected increase in climate hazards, in combination with high regional vulnerability and exposure make it a prominent 'climate change hotspot' (Giorgi, 2006), with a large number of vulnerable natural systems and socioeconomic sectors (Field et al., 2014; MedECC, 2020). In addition to high temperatures, the main risk factor identified is drought, generally expected to increase in the region, significant already at global warming of only 1.5°C, reaching, for higher warming levels, intensities unprecedented during the past 10 ka (Hoegh-Guldberg et al., 2018). In Southern Europe and North Africa, groundwater recharge and soil water content will consequently decline, especially during summer (Kovats et al., 2014; Niang et al., 2014).

With the changing climate, marine ecosystems have already undergone changes in structure, including the spread of tropical species from the Atlantic Ocean and the Red Sea (*high confidence*) and mass mortality in at least 25 invertebrate species, threatening, along with ocean acidification, marine ecosystems, including seagrass meadows (Hoegh-Guldberg et al., 2014; Nurse et al., 2014; Pörtner et al., 2014; Wong et al., 2014). Endemic marine species are at higher risk of extinction due to limited possibilities for migrating northward (Kovats et al., 2014; Poloczanska et al., 2014; Balzan et al., 2020). Southern and eastern Mediterranean coastal systems with narrow dune belts and often rapid urbanisation are vulnerable to both warming and sea level rise (Seneviratne et al., 2012; Wong et al., 2014; Balzan et al., 2020).

Most Mediterranean land ecosystems are impacted negatively by drier conditions, causing the ranges of many endemic species to shrink, and the health and growth rates of trees to decline (Kovats et al., 2014; Niang et al., 2014; Nurse et al., 2014; Settele et al., 2014). Climate change is expected to increase wildfire risk in the region (Kovats et al., 2014), although earlier estimates of burnt area have been reduced in the most recent assessments to approx. 40–100%, considering that prevention and mitigation actions have successfully reduced this risk so far (Balzan et al., 2020). Wetlands and mountain summits are hotspots for biodiversity loss and extinctions (*medium confidence*) (Jiménez Cisneros et al., 2014; Nurse et al., 2014; IPBES, 2018a; IPBES, 2018b; Balzan et al., 2020). Along with unsustainable land use practices, climate change is projected to increase soil erosion in semiarid areas (Jiménez Cisneros et al., 2014).

The increasing water scarcity was found to be a significant threat to agriculture (Jiménez Cisneros et al., 2014; Kovats et al., 2014; Niang et al., 2014; Mrabet et al., 2020). Associated with increased extreme temperatures, the Mediterranean is expected to become less attractive for tourism (Kovats et al., 2014; Nurse et al., 2014; Wong et al., 2014; Dos Santos et al., 2020). Several critical risks for human health increase due to climate change, including heat waves and vector-borne diseases (Kovats et al., 2014; Nurse et al., 2014; Linares et al., 2020). Adaptation options have been identified for many risks (buildings, water management, coastal protection, etc.) (Murray et al., 2012; Revi et al., 2014; Wong et al., 2014). There are synergies between adaptation and mitigation, for example, renewable energies or nature-based solutions focused on the conservation and restoration of ecosystems (Nurse et al., 2014; Hoegh-Guldberg et al., 2018; Vafeidis et al., 2020).

CCP4.1.3 Observed and Projected Climate Change

The Mediterranean Basin is located in a transition zone between mid-latitude and subtropical atmospheric circulation regimes, with large topographic gradients. The analysis of observed climate changes and their impacts is strongly affected by the imbalance of observations between northern and southern countries, where available time series have often not allowed past climate evolution to be reconstructed over a sufficiently long-time scale (Cramer et al., 2018).

Since the 1980s, Mediterranean atmospheric warming has exceeded global average rates (*high confidence*) (WGI AR6 Chapter 11, Seneviratne et al., 2021; Lionello and Scarascia, 2018; Cherif et al., 2020). Future annual and summer warming rates are projected to be 20% and 50% larger than the global annual average, respectively. Summer warming is projected to be particularly strong in the north (Figure CCP4.2, WGI AR6; Chapter 11, Seneviratne et al., 2021; Mariotti et al., 2015; Lionello and Scarascia, 2018). Temperature extremes and heat waves have increased in intensity, number, and length during recent decades, particularly in summer, and are projected to continue increasing (*high confidence*) (WGI AR6 Chapter 11, Seneviratne et al., 2021; Zittis et al., 2016; Hoegh-Guldberg et al., 2018; Cherif et al., 2020).

Sea surface temperatures have increased in recent decades (*high confidence*), with regional variation between +0.29°C and +0.44°C per decade (Darmaraki et al., 2019a), and stronger trends in the eastern basin (Iona et al., 2018; Pastor et al., 2019), involving the whole upper mixed layer (Rivetti et al., 2017). Towards the end of the

3 By tradition, Portugal and Jordan are also considered Mediterranean countries, despite having no Mediterranean coastline.

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The Mediterranean region

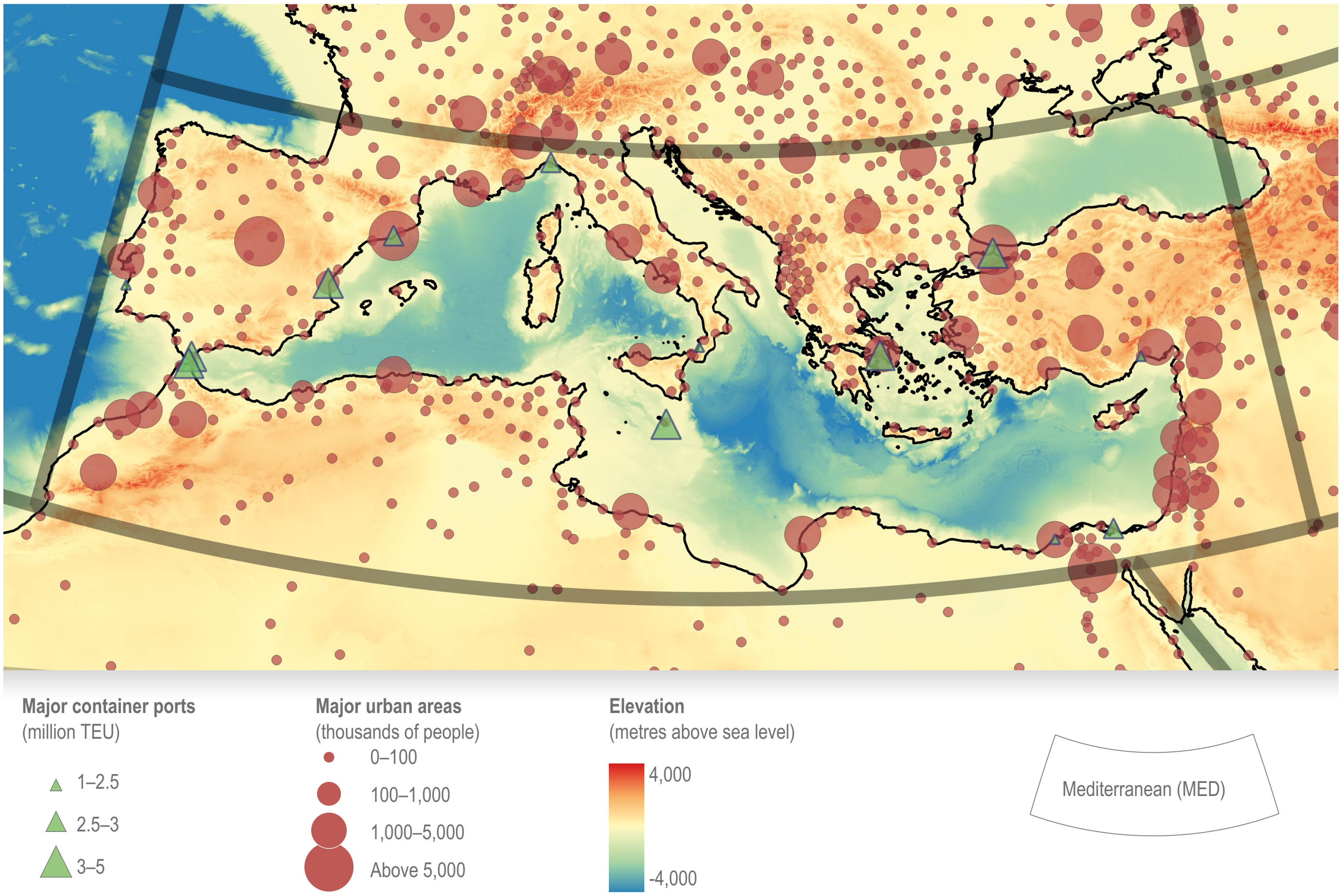

Figure CCP4.1 | The Mediterranean region: Topography and bathymetry (colour bar in metres), main urban areas (population in thousands for 2020 from www.naturalearthdata.com), container ports (millions of TEU [twenty-foot container equivalent units] in 2017, from International Association of Ports and Harbours) and borders of the Mediterranean region used in WGI AR6 Chapter 10 (Doblas-Reyes et al., 2021).

21st century, ocean warming in the range 0.8°C–3.8°C is projected near the surface (*high confidence*), 0.8°C–3.0°C at intermediate depth and 0.15°C–0.18°C in deeper waters (Darmaraki et al., 2019b; Soto-Navarro et al., 2020). The duration and intensity of marine heat waves have increased (*high confidence*) (Darmaraki et al., 2019a) and both parameters are projected to continue increasing in the future (Galli et al., 2017). Under Representative Concentration Pathway (RCP) 8.5, at least one long-lasting marine heat wave is projected for every year by 2100, up to 3 months longer and about four times more intense than present-day events (WGI AR6 Chapter 9, Fox-Kemper et al., 2021; Darmaraki et al., 2019b). Salinity is projected to increase, with anomalies from +0.48 to +0.89 psu by the end of the century (*medium confidence*) (WGI AR6 Chapter 9, Fox-Kemper et al., 2021; Adloff et al., 2015).

Observed trends in annual precipitation are significant only in some areas and some periods, and they are stationary over the long term throughout the region (*medium confidence*) (WGI AR6 Chapter 11, Seneviratne et al., 2021; Figure CCP4.3; Harris et al., 2014; Lionello and Scarascia, 2018; Vicente-Serrano et al., 2020). Precipitation is projected to decrease (*high confidence* for global warming levels above 2°C) (Figure CCP4.2) by approximately 4% per 1°C global warming, for all seasons in the central and southern basin, and mostly in summer in the north (Mariotti et al., 2015; Hertig and Tramblay, 2017; Lionello and Scarascia, 2018). Precipitation extremes have increased in some northern areas (*medium confidence*), and are projected to increase in the north (*high confidence* for global warming levels above 2°C), potentially accompanied by an increase in of flash floods (Llasat et al., 2016), with no change in the south (*low confidence*) (WGI AR6 ATLAS, Gutiérrez et al. 2021; Figures CCP4.2; CCP4.3; Tramblay and Somot, 2018; Lionello and Scarascia, 2020). These trends enhance the gradient between northern (already characterised by more intense events) and southern areas (where extreme precipitation events are comparatively milder) (Giorgi et al., 2014; Jacob et al., 2014; Vautard et al., 2014; Lionello and Scarascia, 2020).

Widespread increase of evaporative demand and some decrease of precipitation explain the drying of the Mediterranean region during recent decades (*high confidence*) (WGI AR6 Chapter 11, Seneviratne et al., 2021; Figure CCP4.3) (Spinoni et al., 2015; Gudmundsson and Seneviratne, 2016; Spinoni et al., 2017; Stagge et al., 2017; Caloiero et al., 2018). Droughts are projected to become more severe, more frequent and longer under moderate emission scenarios, and strongly enhanced under severe emission scenarios (*high confidence*) (WGI AR6 Chapter 11,

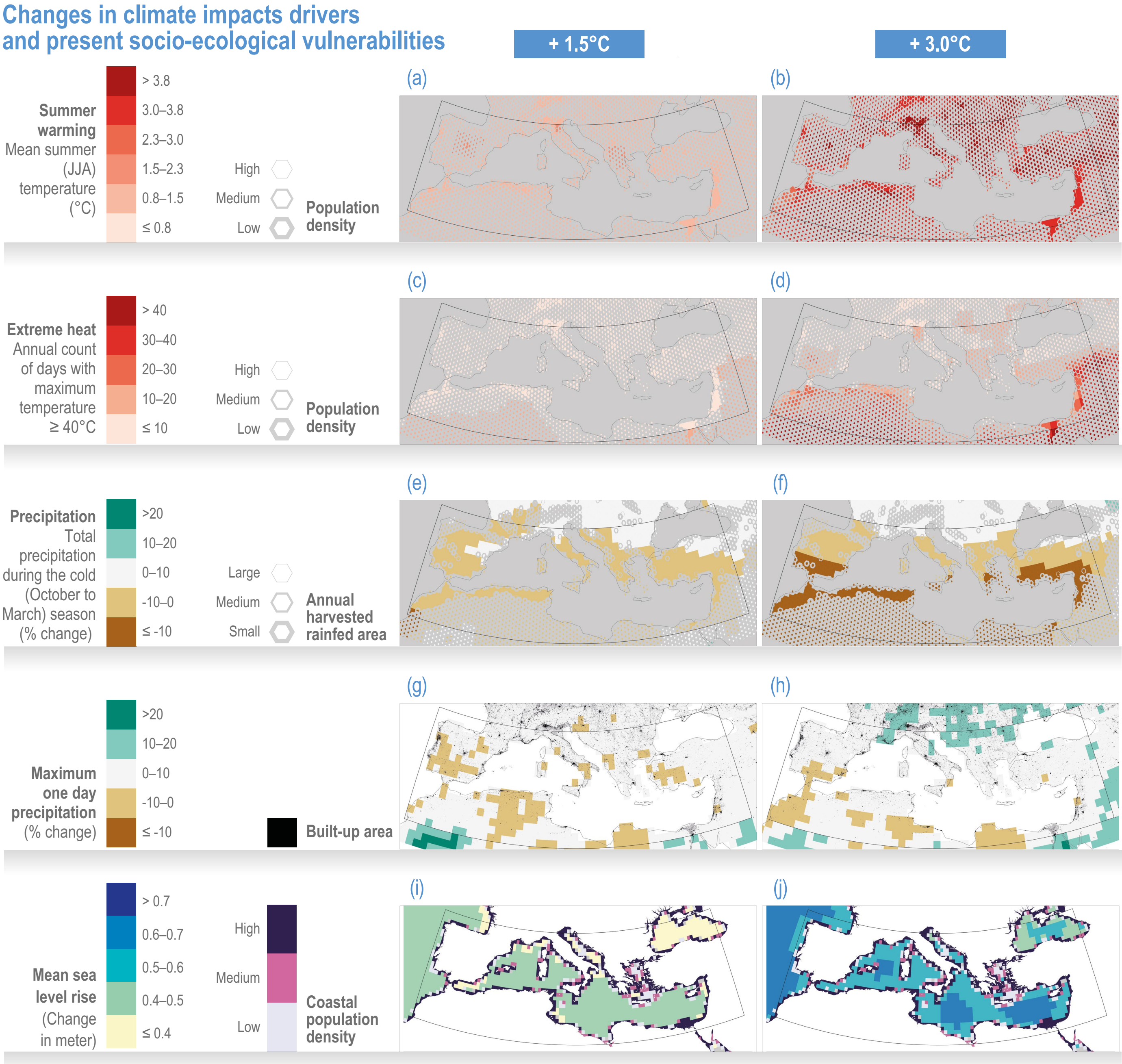

Figure CCP4.2 | Changes in climate impact drivers with respect to the 1995–2014 period for 1.5°C (left column) and 3°C (right column) global warming: mean summer (June to August) temperature (°C, a, b), number of days with maximum temperature above 40°C (days, c, d), total precipitation during the cold (October to March) season (%, e, f) and 1-day maximum precipitation (mm, g, h). Values based on CMIP6 global projections and SSP5-8.5. Sea level rise concerns the long term (2081–2100) and SSP1-2.6 for (i) and SSP3-7.0 for (j) (source: Annex I: Atlas).

Seneviratne et al. 2021; Hertig and Tramblay, 2017; Lehner et al., 2017; Ruosteenoja et al., 2018; Spinoni et al., 2018b; Grillakis, 2019; Lionello and Scarascia, 2020).

No trends in mid-latitude cyclones crossing the Mediterranean Basin have been detected for recent decades (Lionello et al., 2016). For Mediterranean hurricanes ('medicanes'), no observed trends are known because of insufficient monitoring. In the future, mid-latitude cyclones and medicanes are projected to decrease in frequency, but medicane intensity will *likely* increase (Cavicchia et al., 2014; Nissen et al., 2014; Romera et al., 2017).

Mediterranean waters have acidified since the pre-industrial period, more rapidly than the global ocean, due to faster ventilation times (*high confidence*) (Palmiéri et al., 2015). Acidification is projected to continue (*virtually certain*) (WGI AR6 Chapter 11, Seneviratne et al., 2021), with a pH decrease of up to -0.46 in a high emission scenario (Goyet et al., 2016).

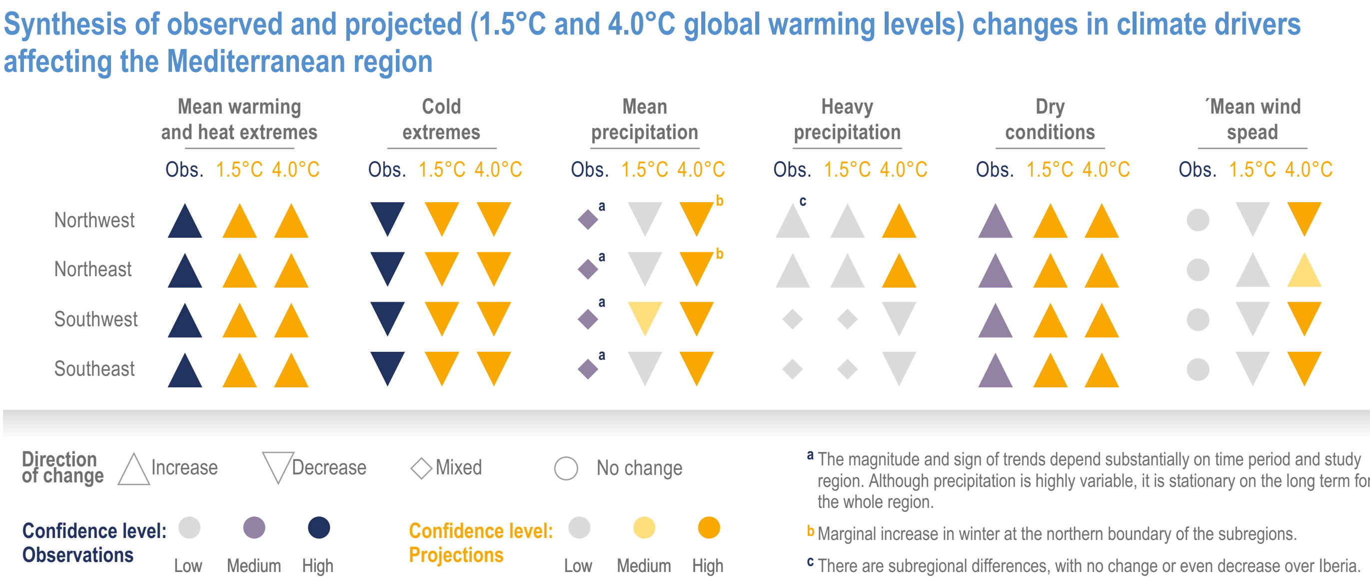

Figure CCP4.3 | Observed and projected (at global warming levels of 1.5°C and 3°C) direction of change of climate drivers and confidence levels for Mediterranean land sub-regions.

Mediterranean mean sea level has risen by 1.4±0.2 mm yr^{-1} during the 20th century (Wöppelmann and Marcos, 2012) and accelerated to 2.4±0.5 mm yr^{-1} for 1993 to 2012 (Bonaduce et al., 2016) and 3.4 mm yr^{-1} for 1990 to 2009 in the northwest (*medium confidence*) (Calvo et al., 2011). The accelerating trend is robust, although different methods and time horizons yield slightly different rates of change (Meyssignac et al., 2011; Cazenave et al., 2018; von Schuckmann et al., 2020). For 2150, sea level is *likely* to reach 0.52 m [0.32–0.81] for SSP1-1.9, to 1.22 [0.91–1.78] for SSP5-8.5 relative to 1996–2014 (*medium confidence*) (WGI AR6 Chapter 9, Fox-Kemper et al., 2021; Figure FAQ CCP4.2; SMCCP4.4), with uncertain variation between sub-basins (Slangen et al., 2017). Melting processes in Greenland and Antarctica could result in even higher levels (*low confidence*, WGI AR6 Chapter 9, Fox-Kemper et al., 2021; Cross-Chapter Box SLR in Chapter 3).

The Mediterranean Basin includes within small distances a large variety of climatic conditions that are *likely* to shift northwards with global warming. Consequently, ecoregions will be exposed to potentially unsuitable conditions: more arid climate for the Mediterranean forests of North Africa, more subtropical climate and temperate climate for the mountain forests of the Balkans and of the Alps, respectively, and Mediterranean climate for the temperate forests of North Anatolia (Figure CCP4.4; Lelieveld et al., 2012; Simpson et al., 2014).

CCP4.1.4 Detection and Attribution of Climate Change Impacts

New evidence published since Working Group II Assessment Report 5 (WGII AR5) confirms that climate change is increasingly affecting many systems and sectors in the Mediterranean region (*high confidence*) (Figure CCP4.5; Chapters 9, 13 and 16). There is *high confidence* that climate change has worsened heat waves and droughts (CCP4.1.3; Lionello et al., 2014; Caloiero et al., 2018; Mathbout et al., 2018; Spinoni et al., 2019), and *medium to high confidence* that heat waves are impacting marine (Rivetti et al., 2014; Tsikliras and Stergiou, 2014; Stergiou et al., 2016; Corrales et al., 2017), freshwater and terrestrial ecosystems (Peñuelas et al., 2018; Bartsch et al., 2020; Carosi et al., 2021), as well as agriculture (El-Maayar and Lange, 2013; Ortas and Lal, 2013; Ponti et al., 2014; Garcia-Mozo et al., 2015; Moore and Lobell, 2015; Oteros et al., 2015; Di Lena et al., 2018) and fisheries (Fortibuoni et al., 2015; Givan et al., 2018; IPBES, 2018a). Heat waves have also increased thermal discomfort, especially in urban areas (WGI AR6 Chapter 10, Doblas-Reyes et al., 2021; WGI AR6 Chapter 12, Ranasinghe et al., 2021; Zinzi and Carnielo, 2017). Despite increasing wildfire hazard, forest fires are generally decreasing in the European part of the basin, due to more efficient risk management (*medium confidence*) (Turco et al., 2016; 2017). Mixed trends of increasing and decreasing flash and river floods across the Mediterranean are reported, but there is *low confidence* in their attribution to climate change (Mediero et al., 2014; Baahmed et al., 2015; Gaume et al., 2016; Paprotny et al., 2018; Blöschl et al., 2019; Vicente-Serrano et al., 2019).

Flooding, erosion and salinisation are significant observed impacts in coastal regions, especially where subsidence is significant, such as in the region of Thessaloniki in Greece or the eastern Nile Delta in Egypt (Raucoules et al., 2008; Frihy et al., 2010), with only *low confidence* in attribution to climate change so far (Section SMCCP4.1). Coastal urbanisation and engineering protection are expanding in the Mediterranean, resulting in substantial impacts on coastal biodiversity (Masria et al., 2015; Carranza et al., 2020).

The attribution of impacts displays little variability across sub-regions, but confidence in attribution to climate change is higher in the north, due to the larger number of observations and studies in Europe. While land use and fisheries are still major non-climatic drivers of changing hazards and biodiversity losses (Aguilera et al., 2015; Turco et al., 2016; IPBES, 2018a; 2018b; Tramblay et al., 2019; Vicente-Serrano et al., 2019), impacts of climate change are now being observed in all parts of the Mediterranean region (*high confidence*).

Bioclimatic regions (Köppen-Geiger classification) and terrestrial biodiversity hotspots in the Mediterranean region

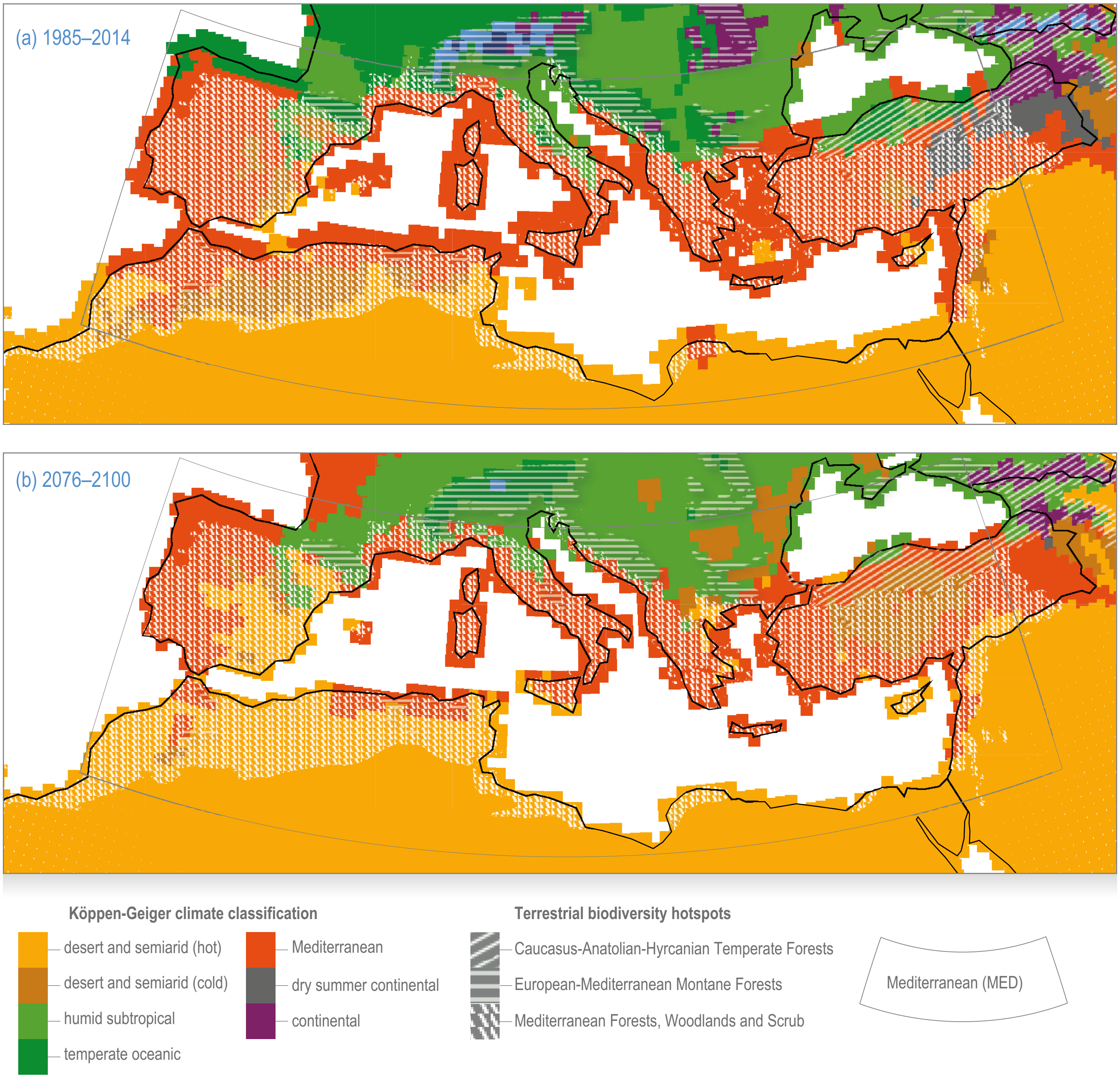

Figure CCP4.4 | Climate and natural land ecosystems in the Mediterranean Basin, based on Köppen-Geiger climate types, for the baseline climate (a, 1985–2014) and the future climate (b, 2076–2100, A1FI scenario (corresponding to global warming of approximately 4°C), based on (Rubel and Kottek, 2010), with the three terrestrial biodiversity hot spots that are present in the region (see WG2 Cross-Chapter Paper 1: Biodiversity Hotspots).

Attribution of observed impacts of climate change in the Mediterranean region

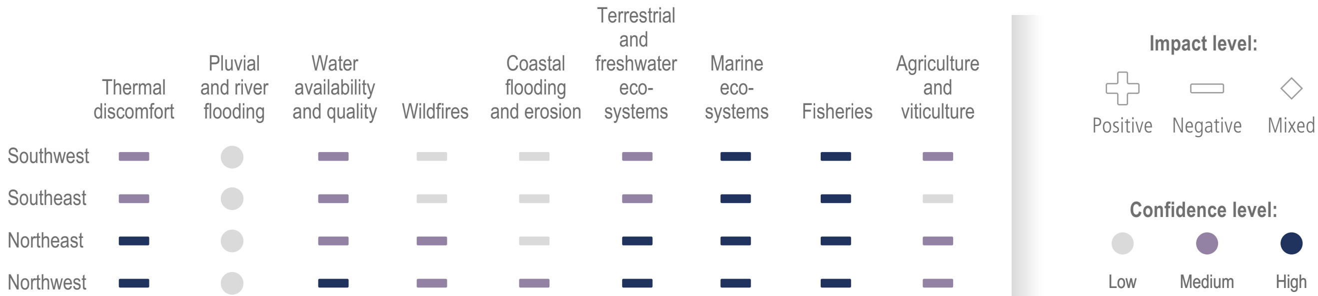

Figure CCP4.5 | Attribution of observed impacts of climate change in the Mediterranean region (see SMCCP4.1 for supporting references).

CCP4.2 Vulnerability of Mediterranean Countries to Climate Change

CCP4.2.1 The Specific Vulnerability of Mediterranean Countries

The Mediterranean region is predominantly vulnerable to the impacts of warming, notably prolonged and stronger heat waves, increased drought in an already dry climate and risk of coastal flooding (Section CCP4.1). southern and eastern countries are generally more vulnerable than countries in the north. Several countries (Tunisia, Algeria and Libya) are below the water scarcity threshold set by the Food and Agriculture Organization of the United Nations (FAO); others (Morocco) are close to the threshold for severe water stress. Uncertainties regarding the timing, duration, intensity and interval between extreme climatic events put some sectors, such as agriculture and tourism, at particular risk in the Mediterranean region (Section CCP4.3; Kallis, 2008; Kutiel, 2019).

CCP4.2.2 Economic Vulnerability

All Mediterranean countries are vulnerable to climate change across most socioeconomic sectors. In low-income countries of the Basin, a 1.1-point reduction of gross domestic product (GDP) could occur as a consequence of 1°C rise warming (Radhouane, 2013). In Morocco, GDP impacts of climate change could be -3% to +0.4% by 2050 relative to 2003 (Ouraich and Tyner, 2018). In Middle East and North Africa (MENA) countries, approximately 10–13% of GDP loss is projected for an increase in global mean temperature of 4.8°C by 2100 (Kompas et al., 2018). In Southern Europe, mean labour productivity loss would shrink by approximately 2% under 2°C warming, along with a GDP loss of 0.1% by the 2030s, reaching 0.4% by the 2080s (Szewczyk et al., 2018).

Freshwater resources are vulnerable to climate change and growing demand, notably from agriculture (Section 4.1.3; Gudmundsson et al., 2017; Zabalza-Martínez et al., 2018; Masseroni et al., 2020). The share of GDP and population exposed to high or very high water stress in MENA countries is 71% and 61%, respectively, compared to 22% and 36% in the world (World Bank, 2018). Freshwater resources are also vulnerable to sea level rise and associated salinisation (Ali and El-Magd, 2016; Wassef and Schüttrumpf, 2016; Twining-Ward et al., 2018). Due to the impact of climate change on water supplies (–14% to –6%), MENA countries are projected to experience high losses in GDP by 2050 (World Bank, 2016).

The agricultural sector is important for most Mediterranean economies, both in terms of GDP and employment, with its share of the total GDP in the region at 6.7% in 2016 (Kutiel, 2019). Water stress in southern countries is largely driven by growing demand from agriculture, with a potential water deficit of 28–47% by 2030 (Sebri, 2017). In Spain, 11 out of 15 river basin districts are under water stress due to demand from agriculture (Vargas and Paneque, 2019). In Greece, the largest agricultural region (Thessaly) where 70% of the irrigation water comes from groundwater, is under water stress (Gemitzi and Lakshmi, 2018). Water scarcity and high dependence on rain-fed agriculture make MENA countries vulnerable to warming and reduced rainfall, associated with high irrigation requirements (Dhehibi et al., 2015; Fader et al., 2016; World Bank, 2016; 2018; Asseng et al., 2018). This is exacerbated by poverty and political instability (Price, 2017). For cropping systems in MENA countries, the Nile Valley and the western parts of North Africa on the Atlas Mountains are classified as the areas with highest vulnerability (ESCWA, 2017). Grassland and pastoral systems are also vulnerable to increasing drought, notably in the western part of the basin (Balzan et al., 2020). Increased heat stress in summer negatively impacts animal health and welfare, i.e., increased incidence of diseases and mortality or lower fertility (Lacetera 2019).

As MENA countries are net food importers, they are not only vulnerable to the impact of climate change on food production in the Mediterranean region, but also the climate impacts on food production elsewhere, for example, in China and Russia (Waha et al., 2017). The agri-food sector in the Mediterranean region is also important for global food security because several large producing countries in the region, such as France, Italy and Morocco, are net exporters of many essential micronutrients to low- and lower-middle-income countries. Changing quantity and quality of production would have direct (availability) and indirect (price signals) impacts on their trade partners.

The economic value of fisheries in the Mediterranean Sea is over USD 3.4 billion (Randone et al., 2017), with about 76,250 fishing vessels in 2019 (FAO, 2020), most of them (about 62%) in the eastern and central Mediterranean (FAO, 2018). Total employment on-board fishing vessels is 202,000 and six countries, Tunisia, Algeria, Turkey, Italy, Greece and Egypt, account for approximately 82% of total employment (FAO, 2020). About 78% of the fish stocks in the Mediterranean are currently fished at unsustainable levels (Galli et al., 2015). The share of stocks in overexploitation has decreased from 88% in 2012 to 75% in 2018 (FAO, 2020). Nearly half of the catches consist of small pelagic species (anchovies, sardines, herrings), which are very vulnerable to increased seawater temperatures (FAOSTAT, 2019). Turkey is particularly sensitive to climate change in the fisheries sector (Turan et al., 2016; Hidalgo et al., 2018). Fisheries in northern countries are less vulnerable because they have a greater capacity to adapt (i.e., more assets, flexibility, learning potential and social organisation), while southern countries are more vulnerable (Ding et al., 2017). The reduction of fish availability directly impacts the income of employees, for example, in the Italian fisheries industry (Tulone et al., 2019).

Mediterranean forests are diverse and play a major ecological and social role through significant ecosystem services, including wood, but also their recreational value and production of non-wood goods, such as mushrooms (Ding et al., 2016; Peñuelas et al., 2017; Gauquelin et al., 2018; Herrero et al., 2019). Many forests grow at the dry margin of their distribution area; therefore, projected drier conditions will affect their productivity and health (Doblas-Miranda et al., 2017; Dorado-Liñán et al., 2019; Sangüesa-Barreda et al., 2019). Vulnerability to wildfire is a significant matter of concern, particularly in the northern and southwestern Mediterranean region (Ager et al., 2014; Gomes da Costa et al., 2020). In Córdoba (Spain), for example, fire suppression costs have increased by 66–87% in the last decade (Molina et al., 2019).

The Mediterranean region accounts for one-third of global tourism with 330 million tourists in 2016 (Tovar-Sánchez et al., 2019). Before the COVID-19 crisis, international tourist arrivals were assumed to increase by 60% between 2015 and 2030, reaching 500 million. In 2015, tourism supported 15% of the total employment in the region (Randone et al., 2017). France, Spain, Italy and Greece are the top tourist destinations (UNWTO, 2016), but the highest growth was in Turkey, Croatia and Albania during 1995–2015 (MGI, 2017). The tourism industry is vulnerable to climate change, particularly in low-income countries (Dogru et al., 2016; Dogru et al., 2019). Coastal tourism in the region generates USD 300 billion annually followed by marine tourism (USD 110 billion) (Radhouane, 2013; Randone et al., 2017).

By providing around 550,000 jobs in the Mediterranean region, the maritime transport and trade industry comprises approximately 20–40% of GDP. As a hub for trade, the Mediterranean, with approximately 600 ports of different sizes, accounts for 25% of all international seaborne trade, including 22% of oil trade. In the region, the shift to green energy to combat climate change would significantly influence the structure of foreign trade in terms of commodities and maritime energy transport flows (Manoli, 2021).

CCP4.2.3 Social and Human Vulnerability

With population growth, food demand in the region increases and will continue to do so, while regional food production on land and from the sea is threatened by climate change, creating the need for additional import. In MENA countries, livestock production increased by 25% in 1993–2013, causing animal feed imports to increase to about 32% of the total food import in 2014 (FAO, 2018), thereby increasing food import dependence of southern countries (INRA, 2015; Saladini et al., 2018). Sharp increases in international food prices since 2007 have caused inflation, trade deficits, fiscal pressure, increased poverty and political instability, all affecting food supply, notably in the south and east of the region (Harrigan, 2011; Kamrava and Babar, 2012; Ferragina and Canitano, 2015; Paciello, 2015).

Heat waves and other climatic extremes affect densely populated urban centres and coastal regions, causing health risks for vulnerable groups, in particular those who live in poverty with substandard housing (Paz et al., 2016; Scortichini et al., 2018; Rohat et al., 2019). Nights with temperatures higher than 23°C have been increasing, with a corresponding increase in health risks (Royé, 2017). Human health is also vulnerable to other risks altered by climate change, either directly through droughts, floods, fires and so forth or indirectly through impacts on disease vectors, air pollution, water quality and food security (Negev et al., 2015). Cases of dengue fever were recently reported from several countries, and there is an apparent threat of outbreaks transmitted by *Aedes* mosquitoes in the northern Mediterranean (Semenza et al., 2016; Semenza and Suk, 2017). The most vulnerable to climate impacts are the elderly, pregnant women, children, the chronically ill, the obese and people with cognitive impairment (Linares et al., 2015; Paravantis et al., 2017).

One-third of the Mediterranean population (about 150 million people) currently lives close to the sea, often in growing urban regions and with infrastructure vulnerable to sea level rise (Cross-Chapter Box SLR in Chapter 3; Briche et al., 2016; UN DESA, 2017). Future exposure to sea level rise is related to demographic growth. All SSPs project an increase of coastal population in the Mediterranean region to 2050. By 2100, coastal population could grow by up to 130%, mostly in the south, but it could also drop by 20% for SSP1 (Reimann et al., 2018b). Overall, countries in the southeastern Mediterranean are most vulnerable to coastal risks, but the exposure is also high in the northern Mediterranean (Satta et al., 2017).

In terms of the number of people, Egypt, Libya, Morocco and Tunisia are the most exposed countries to sea level rise (World Bank, 2014), and this difference is projected to increase under SSP2-4 (Reimann et al., 2018a). Among MENA countries, Egypt is particularly exposed with several coastal cities at risk of inundation (Frihy et al., 2010; Solyman and Abdel Monem, 2020; Elshinnawy and Almaliki, 2021). In the Nile Delta, between 1500 and 2600 km^2 of land are projected to be exposed to flooding by 2100 by a sea level rise of 0.75 m (median sea level rise scenario for SSP5-85) and additional subsidence up to 0.25 m, threatening around 6.3 million residents (Figure CCP4.6; Ali and El-Magd, 2016; Solyman and Abdel Monem, 2020). Basin-wide economic losses are estimated at USD 5 billion, assuming a rise of sea levels by 1.26 m in 2100 (Frihy et al., 2010; World Bank, 2014).

The Mediterranean area is characterised by high human mobility, mostly within countries, but also between them (Cross-Chapter Box MIGRATE in Chapter 7; Charef and Doraï, 2016; Ben Youssef et al., 2017). In 2017, the value of remittances from migrants was about 16% of southern Mediterranean countries' exports to the European Union (EU) (Alcidi et al., 2019). Impacts of recent climate change, notably

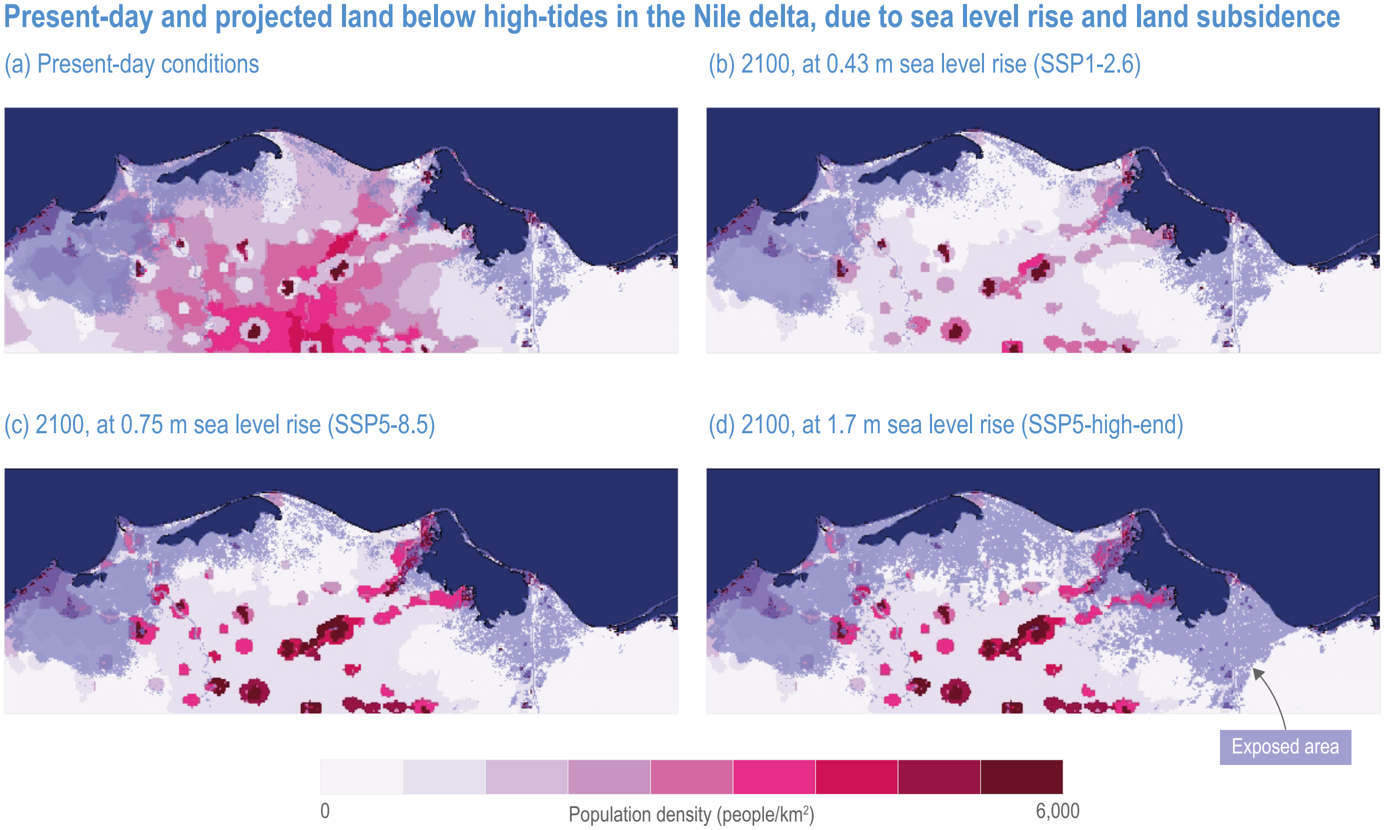

Figure CCP4.6 | Present-day and projected exposure to sea level rise in the Nile Delta, due to sea level change and land subsidence: (a) current exposure, (b) exposure for 2°C of global warming by 2100, (c) exposure for 3°C of global warming by 2100, (d) exposure for a high-end sea level rise scenario involving additional mass losses from the Antarctica ice sheet (Frihy et al., 2010; Ali and El-Magd, 2016; Kulp and Strauss, 2019); sea level scenarios from WG1 AR6 Chapter 9, Fox-Kemper et al., 2021; see Chapter 4 Supplementary Material for additional details.

drought and their effects on human livelihoods and vulnerability, may have contributed to migration decisions, although there is debate about the relative importance (Kelley et al., 2015; Fröhlich, 2016; Hamed et al., 2018; Ash and Obradovich, 2020). One study of five MENA countries estimated that extreme climate events account for about 10–20% of migration, with an expected increase of the role of environmental factors in the future as climatic conditions deteriorate further (Wodon et al., 2014).

Improved sharing and co-production of knowledge can support climate adaptation practices, ensure their implementation and thereby reduce vulnerability (Nguyen et al., 2019), for example, in the water sector (Iglesias and Garrote, 2015; Iglesias et al., 2018) and notably river management (Tàbara et al., 2018). The individual perception of climate risks is also a component of vulnerability (Nguyen et al., 2016). Understanding the gap between perceptions and scientific evidence, and increasing risk perception and awareness, will be crucial to promote adaptive responses both at the individual and the collective level throughout the Mediterranean Basin (Macias et al., 2015; Bodoque et al., 2016; Cramer et al., 2018).

CCP4.3 Projected Climate Risks in the Mediterranean Basin

CCP4.3.1 Ocean Systems

With warming, marine primary production is projected to decrease in the western and increase in the eastern Mediterranean Sea (Macias et al., 2015). The diversity of copepods (species which dominate the meso-zooplankton communities feeding Mediterranean fishes) is projected to decline over most of the Mediterranean, albeit with regional variation (Benedetti et al., 2018). Total marine biomass (and fishery potential) is projected to increase in the southeastern Mediterranean, whereas significant decreases are most likely in the west (Moullec et al., 2019). The projected increase of marine heat waves in the Mediterranean Sea will add additional pressures to coastal and marine ecosystems. Warm-water fish species are expected to move northwards, while cold-water species will decline, and invasions of thermal-tolerant tropical species will increase (*high confidence*) (Lloret et al., 2015; Corrales et al., 2018). Fish species richness is predicted to increase in the eastern and decrease in the western Mediterranean by 2050 but, by 2100, the cooler areas in the north will become a 'cul-de-sac' for many species (Albouy et al., 2013; Burrows et al., 2014). Out of 75 endemic fish species, 14 are projected to go extinct, almost all of them benthic and demersal species (Ben Rais Lasram et al., 2010). The abundance of small and medium-sized pelagic fish (e.g., European anchovy) is projected to decline by 15–33% by 2100 (Stergiou et al., 2016; Raybaud et al., 2017).

Heat waves will *likely* cause increasing mass mortality events of benthic species, mostly invertebrate organisms, such as corals, sponges, bivalves, ascidians and bryozoans, increasing the risks of abrupt collapse of endemic species (Kersting et al., 2013; Rivetti et al., 2014; Rivetti et al., 2017; Garrabou et al., 2019; Garrabou et al., 2021). Deep-water corals live near their upper thermal tolerance and further warming could thus reduce their biotic potential and long-term survival (Nannini et al., 2015; Yasuhara and Danovaro, 2016; Marchini et al., 2019), although there are some exceptions (Naumann et al., 2013) and also knowledge gaps (Maier et al., 2019). Warming has been shown to severely reduce the metabolism of some Mediterranean coral species (Gori et al., 2016). In summary, the observed shift in marine ecosystems since 1980 is projected to continue and intensify, resulting in very high risks for marine ecosystems between 1.5°C–2°C global warming levels (GWL) (Figure CCP4.8; Chapters 3; 13; CCP1; Manes et al., 2021).

CCP4.3.2 Coastal Systems

Sea level rise is the origin of multiple risks for low-lying areas in the Mediterranean Basin; for example, the further increase in flooding at high tide in some locations, such as Venice (*high confidence*) (Chapter 13; Cid et al., 2016; Pomaro et al., 2017). Currently, 37% of coastal areas are at moderate to high risk from coastal erosion and flooding (Satta et al., 2017). Due to rapid urban development, many coastal assets are directly exposed to projected sea level rise and coastal hazards, with limited adaptation options and resilience of beaches (Section CCP4.2;Brown et al., 2016; Jiménez et al., 2017).

The Mediterranean is a micro-tidal sea, where storms may hit the coast over several hours or longer, and not only during high tides (Le Cozannet et al., 2015; Sánchez-Arcilla et al., 2016; Sierra et al., 2016; Sayol and Marcos, 2018). Projected changes of winds, storms and waves are small, and confidence in these changes is limited by the quality of climate models applied to the Mediterranean (Calafat et al., 2014; Androulidakis et al., 2015; Vousdoukas et al., 2017). Overall, sea level rise is projected to increase the risk of coastal flooding despite the potential slight reductions of marine storms (*high confidence*) (Lionello et al., 2017; Vousdoukas et al., 2017). Risks of erosion and flooding will be amplified with climate change, particularly in river deltas (Figure CCP4.6; Ali and El-Magd, 2016), on low-lying floodplains, on sandy beaches around the basin and in many coastal cities (Satta et al., 2017). Impacts are projected to increase nonlinearly during the 21st century with higher sea level rise, because coastal flooding will progressively change from overtopping to overflow, high-tide flooding and ultimately permanent flooding and shoreline retreat (*high confidence*) (Le Cozannet et al., 2015; Sánchez-Arcilla et al., 2016; Sierra et al., 2016; Antonioli et al., 2017; Anzidei et al., 2017; Ciro Aucelli et al., 2017; Enríquez et al., 2017; Jiménez et al., 2017; Sayol and Marcos, 2018). These risks may be amplified further in areas with poor storm water management and sealed urban surfaces (Llasat et al., 2013; Gaume et al., 2016).

Combined with storm surges, sea level rise may disrupt Mediterranean port operations (Sánchez-Arcilla et al., 2016; Sierra et al., 2016), with risks depending on adaptation, physical protection measures and basin depth. Risks for deep ports are more limited (Sierra et al., 2017), while low-depth small harbours, common in the Mediterranean, could be significantly affected (Sierra et al., 2016). Sea level rise may enhance sandy beach erosion and thereby impact recreation and tourism (Bitan and Zviely, 2018; Rizzetto, 2020), magnifying coastal degradation and pollution (Enríquez et al., 2017; Gössling et al., 2018).

CCP4.3.3 Inland Ecosystems

Beyond 3°C GWL, 13–30% of the Mediterranean Natura 2000 protected area and 15–23% of Natura 2000 sites are projected to change towards more arid ecosystem types (Barredo et al., 2016). Biodiversity and ecosystem services would be exposed to degradation of wetland hydrology, which could affect 19–32% of localities under a 1.5°C–2°C GWL (48–73% under higher warming), particularly in Spain, Portugal, Morocco and Algeria (Lefebvre et al., 2019). There is also a substantial shrinking of terrestrial and freshwater ecosystem habitats, in particular in Mediterranean islands (Chapters 2; 4; CCP1).

Increased aridity impacts forest ecosystems (Costa-Saura et al., 2017; García Sánchez et al., 2018). Increasing heat waves, combined with drought and land use change, reduce fuel moisture, thereby increasing fire risk, extending the duration of fire seasons and increasing the likelihood of large, severe fires (*high confidence*) (EEA, 2017; Lozano et al., 2017; Peñuelas et al., 2017; Varela et al., 2019). Fires impact vegetation recovery after abandonment, thus transforming landscapes (González-De Vega et al., 2016). At warming levels of 1.5°C, 2°C and 3°C, burnt area in Mediterranean Europe could increase by 40–54%, 62–87% and 96–187%, respectively (Turco et al., 2018b), although changes are highly site dependent and also affected by management (Caon et al., 2014; Wu et al., 2015; Parra and Moreno, 2018; Brotons and Duane, 2019; Hinojosa et al., 2019).

Desertification occurs in large parts of the region, generally due to unsustainable land use (Peñuelas et al., 2017). Increasing drought is projected to exacerbate desertification in North Africa and, under high warming, also southern Spain. In some areas, sclerophyllous vegetation could replace deciduous forests (Guiot and Cramer, 2016). Increasing temperatures and drought could trigger dieback for some forest species such as Mediterranean oak (Sánchez-Salguero et al., 2020), potentially also in combination with biotic factors such as pathogens (Matías et al., 2019).

CCP4.3.4 Water, Agriculture and Food Production

River runoff and low flows are expected to decrease (possibly by 12–15% or more) in most locations due to reduced precipitation (Giuntoli et al., 2015; Roudier et al., 2016; Andrew and Sauquet, 2017; Gosling et al., 2017; Marchane et al., 2017; Marcos-Garcia et al., 2017; Marx et al., 2018; Yeste et al., 2021). Groundwater recharge is projected to decrease due to reduced inflow (WGI AR6 Chapter 11, Ranasinghe et al., 2021; Koutroulis et al., 2016; Guyennon et al., 2017; Braca et al.,

Table CCP4.1 | Projected risks for crop production in the Mediterranean Basin.

Crop	Projected risk
Cereals and rice	Under 2°C warming and beyond, rain-fed wheat yield in most locations could decline by 2–59%, depending on agricultural practices (Chourghal et al., 2016; Dettori et al., 2017; Iocola et al., 2017; Brouziyne et al., 2018; Kheir et al., 2019). Under 1.5–3°C warming and reduced rainfall, yield decreases are also projected for maize (Georgopoulou et al., 2017; Iocola et al., 2017) and barley (Bouregaa, 2019; Cammarano et al., 2019), mainly due to the shortening of the crop growing season by up to 30 days due to higher temperatures (Saadi et al., 2015; Bird et al., 2016; Waha et al., 2017; Bouregaa, 2019). In Tunisia, cereal production may decrease by 0.79% with a 1% decrease in precipitation (Zouabi and Peridy, 2015). Reductions of rice yields in parts of the region are projected in the absence of adaptation; for example, by 6–20% in southern France and Italy in 2070 under RCP8.5 (Bregaglio et al., 2017).
Olives	Higher temperatures and more frequent extreme heat events around flowering will *likely* affect phenology. While suitable areas for olive cultivation could extend northward and to higher elevations under the A1B scenario in 2036–2065 (Tanasijevic et al., 2014), negative consequences for several countries are expected, including southern Spain (Gabaldón-Leal et al., 2017; Arenas-Castro et al., 2020) and Tunisia (Ouessar, 2017) under 2°C warming. Under 1.5°C–2°C GWL, olive yields in northern Mediterranean locations could decrease by up to 21% (Brilli et al., 2019; Fraga et al., 2020). A 3°C warming could cause a 15–64% drop of production of rain-fed olives in Algeria (Bouregaa, 2019).
Vegetables	Yields could decline by up to 45% under current irrigation in some areas by 2050 under the A1B scenario (Zhao et al., 2015; Georgopoulou et al., 2017), while a lower availability of irrigation water would lead to further losses (Saadi et al., 2015) or even to non-viability of crops in some locations; for example, in Tunisia beyond 2°C warming (Bird et al., 2016).
Fruit trees	Flowering of many fruit trees may be delayed, and chilling accumulation may be threatened. In Spain, under the A2 scenario, apples at maturity could be of inferior quality from mid-century, while after 2070, 28–72% of the years could have winters that do not fulfil chilling requirements (Rodríguez et al., 2019) Similar threats for other fruit trees were found beyond 3°C GWL (Funes et al., 2016).
Grapevines and orchards	Climate change could advance bud break and flowering, shortening the growing season by 20–35 days after 2060 under RCP8.5 (Fraga et al., 2016; Ramos, 2017; Leolini et al., 2018; Ramos et al., 2018) and shifting maturation under high summer temperatures, thus affecting grape quality. Higher temperatures may increase evapotranspiration and therefore water deficit (Ramos et al., 2018). Some locations may suffer from high winter temperatures, causing a lack of chilling accumulation and ultimately missed bud break (Leolini et al., 2018). Early maturation may result in unbalanced wine quality through higher sugar and lower acids in the grape must after 2050 under RCP8.5 (Fraga et al., 2016; Koufos et al., 2018). Negative impacts of climate change on table quality vines and wine grape production in Southern Europe after 2040 under RCP8.5 have been projected (Cardell et al., 2019).
Dates	Irrigation requirements for date palms in Tunisia under RCP8.5 could increase by 34% in 2050 from present to sustain date production (Haj-Amor et al., 2020), with adverse effects on groundwater resources.

2019; Calvache et al., 2020). Water levels in lakes and availability of reservoirs are expected to decline by up to 45% in 2100 (Koutroulis et al., 2016; Masia et al., 2018; Okkan and Kirdemir, 2018; Braca et al., 2019; Tramblay et al., 2020). The largest freshwater lake in the basin, Lake Beyşehir (Turkey), could dry out after 2070 (Bucak et al., 2017). In northern Africa, surface water availability is projected to be reduced by 5–40% in 2030–2065 and by 7–55% in 2066–2095 from 1976–2005 (Tramblay et al., 2018), with decreases of runoff by 10–63% by mid-century in Morocco and Tunisia (Marchane et al., 2017; Dakhlaoui et al., 2020). Reduced summer river flows and increasing water temperatures will constrain freshwater-cooled thermoelectric (including nuclear) power plants and hydropower plants, with possible reductions of production in the northern Mediterranean by 6–33% under 2°C and by 20–60% beyond 3°C warming (Lobanova et al., 2016; Solaun and Cerdá, 2017; Payet-Burin et al., 2018; Tobin et al., 2018).These findings confirm the WGI AR6 Chapter 8 statement that drought duration and frequencies and water scarcity are projected to increase drastically between 1.5°C and 2°C of GWLs (Douville et al., 2021).

Climate change will *likely* reduce crop yields in many areas (Table CCP4.1), mainly due to higher temperatures affecting crop phenology and the shortening of the crop growing season (*high confidence*). Additional irrigation will be needed for most crops, although the shortening of the growing season could reduce irrigation needs in some cases (Saadi et al., 2015). Irrigation needs could increase by 25% in northern and two-fold in southeastern Mediterranean (Fader et al., 2016), with arid southern areas at risk of insufficient water resources by 2100. The use of supplemental irrigation for winter wheat could become more common in northern Mediterranean (Saadi et al., 2015; Ruiz-Ramos et al., 2018).

Seawater intrusion is projected to cause additional risks in coastal aquifers, with severe impacts on agricultural productivity (Ali and El-Magd, 2016; Wassef and Schüttrumpf, 2016; Pulido-Velazquez et al., 2018; Twining-Ward et al., 2018; Omran and Negm, 2020). While elevated atmospheric CO_2 concentration could be positive for photosynthesis and cereal yields (Dixit et al., 2018; Ben-Asher et al., 2019; Kapur et al., 2019; Kheir et al., 2019), the net outcome for agricultural production is highly uncertain (Moriondo et al., 2016). The projected yield losses will *likely* reduce farm revenues, for example, in Morocco (Ouraich and Tyner, 2018), Egypt (Abd El-Azeem, 2020), Greece (Georgopoulou et al., 2017) and Israel (Zelingher et al., 2019). Given the growing water demand from agriculture and other users and the increasing competition over water resources, adaptation efforts for water supply need to be enhanced (Guyennon et al., 2017; Zabalza-Martínez et al., 2018).

Climate-driven change in pelagic production (Section CCP4.3.1), together with overfishing, will *likely* increase risks for fishery landings (Hidalgo et al., 2018). 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; Balzan et al., 2020). Thermophilic and/or thermal-tolerant tropical species may increasingly dominate the catch composition (Moullec et al., 2019), creating possible opportunities depending on technology and consumer acceptance of new species (Hidalgo et al., 2018). Warming and acidification may weaken mussel shells, negatively impacting shellfish aquaculture (Martinez et al., 2018). High losses of clawed lobster production by the end of the century are projected under RCP4.5 (Boavida-Portugal et al., 2018). For much of the region, fisheries revenue may decrease by 15–30% by 2050 relative to 2000 under RCP8.5 (Lam et al., 2016).

Overall, reduced crop yields and fishery landings, combined with other factors such as rapid population growth and urbanisation, increasing competition for water and changing lifestyles, will *likely* impact food security, particularly in North Africa and the Middle East (Jobbins and Henley, 2015).

CCP4.3.5 Human Health and Cultural Heritage

Warming is projected to impact human health, mostly through increased intensity, frequency and duration of heat waves (*high confidence*) (Guerreiro et al., 2018; Jacob et al., 2018; Rohat et al., 2019; Smid et al., 2019). Under current socioeconomic conditions, 53–93 million more people could be exposed to high or very high heat stress in northern Mediterranean by 2050 (Rohat et al., 2019) and heat-related excess mortality could increase by more than six-fold above 3°C GWL (Gasparrini et al., 2017). In MENA countries, the mortality risk of the elderly in 2100 could be 8–20 times higher under RCP8.5 compared to 1951–2005, and still 3–7 times higher under RCP4.5 (Ahmadalipour and Moradkhani, 2018). Deaths attributable to high temperatures in the northern Mediterranean could increase by 18–20,000 in 2050 (50,000 in 2100) under RCP8.5 (1.4 and 2.6 times lower under RCP4.5) (Kendrovski et al., 2017).

Climate change and variability may also influence the emergence of vector-, food- and water-borne diseases (Negev et al., 2015). Under RCP8.5, the epidemic potential of dengue fever in Southern Europe is projected to increase by 2100 (Liu-Helmersson et al., 2019), as well as the risk of infections by West Nile virus in 2050 under A1B (Semenza et al., 2016). Climate-induced diseases could reduce labour productivity in the region by 2060, particularly in MENA countries (Dellink et al., 2019). Overall, there is still uncertainty in projections of the future severity and distribution of diseases because of climate change due to the complex interactions between hosts, pathogens and vectors. Reductions in fruit and vegetable consumption as a result of climate change on food availability could lead to more than 20,000 deaths in 2050 under RCP8.5 from diseases caused by malnutrition (Springmann et al., 2016).

Extreme high temperatures, hot days and nights and consequently cooling degree days will *likely* increase (*high confidence*) (Spinoni et al., 2018a; Coppola et al., 2021), with specific cooling needs in cities possibly increasing by 50–278% under 2°C GWL and 134–375% beyond 3°C GWL (Cellura et al., 2018). Urban heat island effects will further increase cooling needs (Salvati et al., 2017; Zinzi and Carnielo, 2017). Higher temperatures will increase thermal and chemical stress on materials used in many ancient buildings and sculptures, such as marble, stone and masonry (Bonazza et al., 2009; Leissner et al., 2015).

Many studies project a decrease of climatic comfort for tourism in the Mediterranean by 2071 to 2100, particularly during summer (Grillakis et al., 2016; Jacob et al., 2018; Braki and Anagnostopoulou, 2019). There is adaptive potential in the extension of the period with favourable climatic conditions for urban tourism in northern Mediterranean cities (Scott et al., 2016). Water scarcity may create additional constraints for tourism (Köberl et al., 2016).

Cultural heritage sites in the region face risks from coastal flooding, with 37 out of 49 cultural World Heritage sites today facing risk from a 100-year flood, and 42 of them from coastal erosion (Reimann et al., 2018b). Sea level rise will increase these risks (*high confidence*) (Lionello, 2012; Rizzi et al., 2017; Reimann et al., 2018b; Ravanelli et al., 2019; Tagliapietra et al., 2019). By 2100, 47 of the 49 United Nations Educational, Scientific and Cultural Organization (UNESCO) sites are projected to be at risk from coastal flooding or erosion (Reimann et al., 2018b). Beyond 2100, sea levels are committed to rise further and represent an existential threat for the high number of coastal cultural heritage located in the Mediterranean (WGI AR6 Chapter 9, Fox-Kemper et al., 2021; Chapter 13; Cross-Chapter Box SLR in Chapter 3; Marzeion and Levermann, 2014).

CCP4.3.6 Synthesis of Key Risks

For the Mediterranean Basin, all currently projected pathways of climate change will exacerbate climate-related risks in multiple systems and economic sectors, and for human health and well-being, amplifying current pressures on local ecosystems, economies and human well-being (Figures CCP4.7; CCP4.8; Cramer et al., 2018; MedECC, 2020). While the majority of these risks apply across the entire region, many are specific for certain sub-regions or locations.

CCP4.4 Adaptation and Sustainable Development in the Mediterranean Basin

CCP4.4.1 Ocean and Coastal Systems

Adaptation options for climate change impacts on marine ecosystems and fisheries include improving and enlarging the regional network of marine protected areas, transnational management of marine food resources, sustainable fishery practices, developing collaborative monitoring, research and managing knowledge platforms for fisheries (Bjørkan et al., 2020; Raicevich et al., 2020) and sustainable aquaculture (Ehlers, 2016; Lacroix, 2016).

Adaptation options to sea level rise in the Mediterranean include nature-based solutions, such as beach and shore nourishment, dune restoration, or ecosystem-based adaptation and restoration in low-lying coasts, lagoons, estuaries and deltas (Aragonés et al., 2015; Aspe et al., 2016; Loizidou et al., 2016; Danovaro et al., 2018). Engineering plays a major role for coastal adaptation too, through breakwaters, seawalls, dykes, surge barriers and submerged breakwaters (Sancho-García et al., 2013; Becchi et al., 2014; Balouin et al., 2015; Masria et al., 2015; Tsoukala et al., 2015; Bouvier et al., 2017). Many engineering-based coastal adaptation imply large residual impacts on coastal ecosystems (*high confidence*) (Micheli et al., 2013; Masria et al., 2015; Cooper et al., 2016; Bonnici et al., 2018). A sea surface height control dam at the Strait of Gibraltar has been proposed for mitigating sea level rise in the Mediterranean, but this would *likely* involve major impacts on ecosystems and fisheries (Gower, 2015).

Key risks in the Mediterranean and their location for SSP5-RCP8.5 by 2100

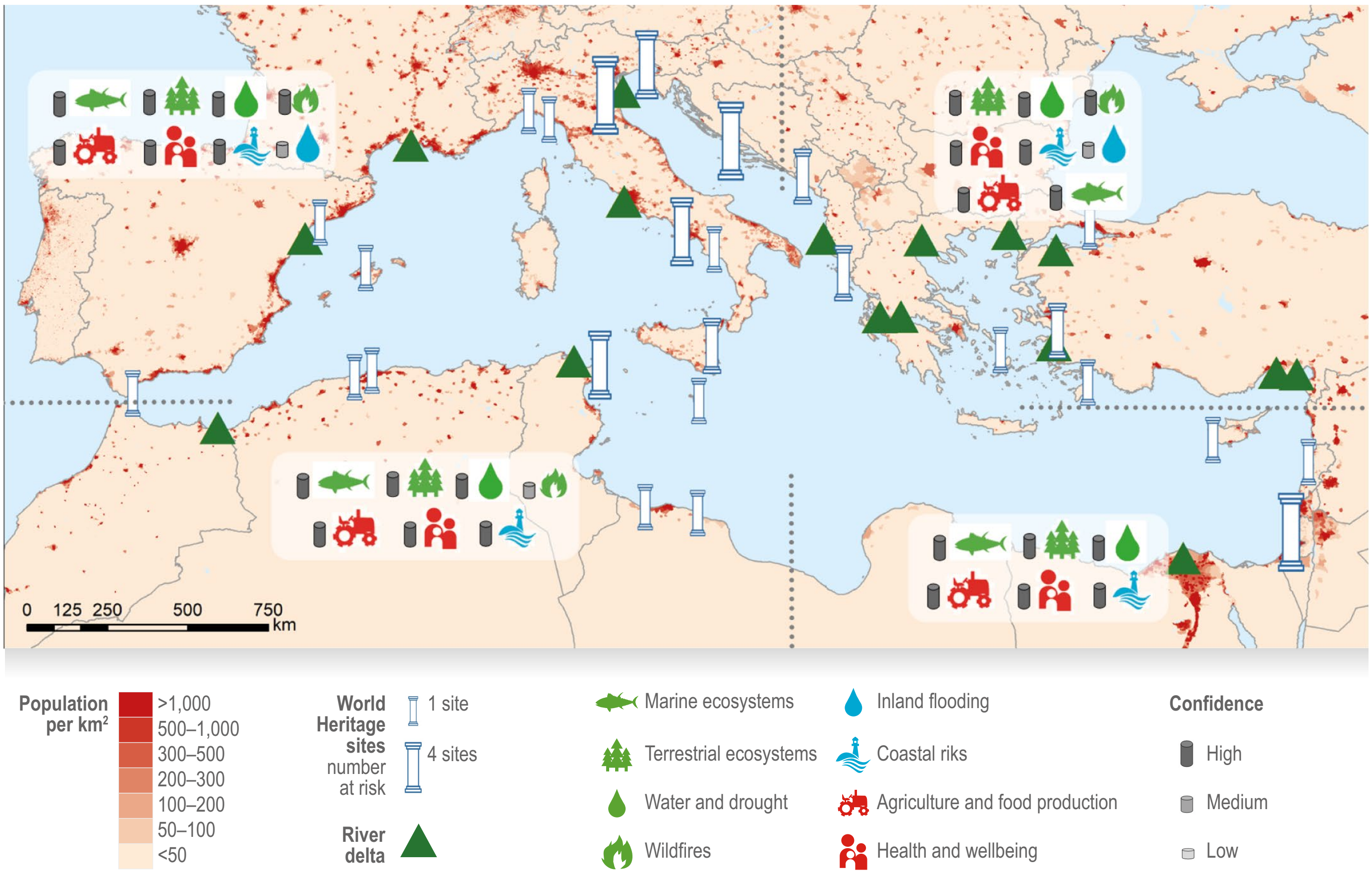

Figure CCP4.7 | Key risks in the Mediterranean and their location across the Mediterranean region for SSP5-RCP8.5 by 2100 (Sections CCP4.3.2–6; Table SMCCP4.2a and b for details). Risks to World Cultural Heritage sites from flooding or erosion due to sea level rise in multiple locations (Section CCP4.3.5) and Mediterranean river deltas are hotspots of vulnerability to climate change (Section CCP4.3.2). The population exposed to risks is mapped for an SSP5-8.5 pathway. Adaptation can reduce these risks (Section CCP4.4) (based on: Reimann et al., 2018a; 2018b; Wolff et al., 2018).

Key risks in the Mediterranean region

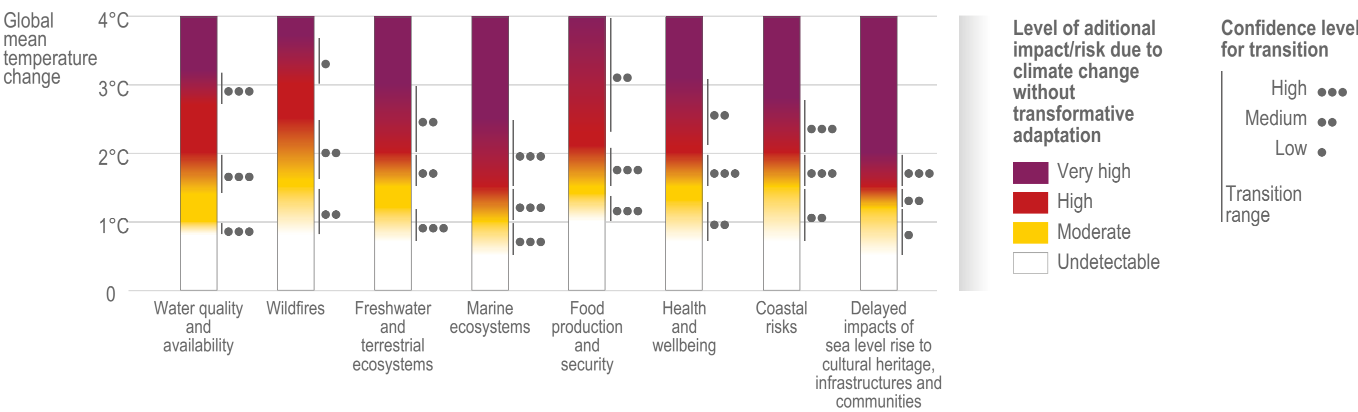

Figure CCP4.8 | Summary of key risks for the Mediterranean (Sections CCP4.3.2–8; Table SMCCP4.2a–h for details). Coastal risks include one burning ember displaying additional risks due to climate change as specific GWL are exceeded (Coastal risks), and one burning ember describing additional risks due to committed sea level rise at timescales of centuries and millennia for long-living infrastructure and cultural heritage (WGI AR6 Chapter 9, Fox-Kemper et al., 2021; Marzeion et al., 2014; Marzeion and Levermann, 2014; Clark et al., 2016; see SMCCP4.2h).

CCP4.4.2 Inland Ecosystems

In forests, adaptation to impacts of warming and drought may involve multiple forest management strategies, such as thinning (Fernández-de-Uña et al., 2015; Giuggiola et al., 2016; Aldea et al., 2017; del Río et al., 2017; Gleason et al., 2017; Lechuga et al., 2017; Vilà-Cabrera et al., 2018), increasing the share of drought-tolerant species and provenances (Hlásny et al., 2014; Calvo et al., 2016), or promoting mixed-species stands (Ruiz-Benito et al., 2014; Guyot et al., 2016; Sánchez-Pinillos et al., 2016; del Río et al., 2017; Jactel et al., 2017; Ratcliffe et al., 2017).

Adaptation options to increased fire risks include improved planning of residential development such as to avoid inevitable wildfire (Schoennagel et al., 2017; Samara et al., 2018), improved fire suppression capacities and strategies (Brotons et al., 2013; Regos et al., 2014; Khabarov et al., 2016; Turco et al., 2018a; 2018b), managing and planning landscape matrix schemes to reduce fire risk (de Rigo et al., 2017; Erdős et al., 2018), thinning, slash management and prescribed burning techniques (Fernandes et al., 2016; 2018; Khabarov et al., 2016; Regos et al., 2016; Piqué and Domènech, 2018; Samara et al., 2018; Vilà-Cabrera et al., 2018; Duane et al., 2019), as well as understory grazing (Varga et al., 2016; Vilà-Cabrera et al., 2018).

Adaptation of forest management generally requires improved monitoring systems of forest condition and natural disturbances (Hlásny et al., 2014; Hengeveld et al., 2015; Maes et al., 2015), supported by participatory forest management and planning processes and local self-governance mechanisms (Bouriaud et al., 2013; 2015).

For freshwater ecosystems, adaptation options include hydrological and land use planning at basin scale, which can be complemented with local conservation and restoration efforts, and the preservation of natural flow variability of rivers and streams (Aspe et al., 2016; Loizidou et al., 2016; Cid et al., 2017; Menció and Boix, 2018; Morant et al., 2020).

CCP4.4.3 Water Management, Agriculture and Food Security

Adaptation options to address water shortages at the national scale include transboundary resource management (Escriva-Bou et al., 2017; Pulido-Velazquez et al., 2018), promoting fair, equitable and sustainable water trade in international markets (Johansson et al., 2016; Lee et al., 2019), regional, national and basin-scale management plans for water resources (Wilhite et al., 2014; Paneque, 2015; Urquijo et al., 2015; Estrela and Sancho, 2016; Vargas and Paneque, 2019), improved groundwater monitoring and strategic management (Pulido-Velazquez et al., 2020), and economic instruments to manage water demand (prices policies, markets and subsidies).

Technical options include the reduction of losses in water distribution networks for drinking water and irrigation (Burak and Margat, 2016; Fader et al., 2016), desalinisation, often combined with generation of electricity (Papanicolas et al., 2016; Bonanos et al., 2017; Jones et al., 2019), artificial recharge of groundwater and subterranean dams (Djuma et al., 2017; De Giglio et al., 2018; Missimer and Maliva, 2018; Baena-Ruiz et al., 2020), and waste water reuse (Kalavrouziotis et al., 2015; Barba-Suñol et al., 2018; Cherfouh et al., 2018). On the demand side, options include changing diet and water consumption patterns (Blas et al., 2016; Gul et al., 2017; Blas et al., 2018), and enhancing water use efficiency in the tourism and food sectors (Hadjikakou et al., 2013; Moresi, 2014).

In the agriculture sector, improved efficiency of irrigation practices can be achieved by changing surface water irrigation for other techniques and shifting to more sustainable practices (Mrabet et al., 2012; Benlhabib et al., 2014; Boari et al., 2015; Ćosić et al., 2015; Guilherme et al., 2015; Iglesias and Garrote, 2015; Cantore et al., 2016; Triberti et al., 2016; AbdAllah et al., 2018; Billen et al., 2018; Iglesias et al., 2018; Malek and Verburg, 2018; Vargas and Paneque, 2019). Overall, the region could save 35% of water resources by improved irrigation techniques (Fader et al., 2016). However, maladaptive drip irrigation subsidies and developments can also result in the unsustainable use of groundwater resources and excessive agriculture intensification, indicating the need for careful strategic planning, regulation and monitoring of these options (Venot et al., 2017). In the livestock sector, adaptation options for heat wave-induced mortality of animals include the choice of more resistant genetic provenances (Rojas-Downing et al., 2017).

Other adaptation options in the agricultural sector include agro-ecological techniques that increase the water retention capacity of soils (mulching, zero tillage, reduced tillage, etc.) (Aguilera et al., 2013a; Aguilera et al., 2013b; Almagro et al., 2016; Sanz-Cobena et al., 2017; Tomaz et al., 2017; Bhakta et al., 2019; García-Tejero et al., 2020) and promoting crop diversification, adapting the crop calendar and the use of new varieties adapted to evolving conditions. Many of these strategies for more sustainable production are also intended to address the food security risks and import dependence in the region. Other options are to manage nitrogen resources, food demand, change diets and reduce food waste (Billen et al., 2018; Schils et al., 2018; Billen et al., 2019; Garnier et al., 2019; Aguilera et al., 2020; Lassaletta et al., 2021).

CCP4.4.4 Human Health

In the Mediterranean region, adapting to increasing heat wave impacts involves local urban health adaptation plans, as well as increasing the capacity of healthcare systems (Fernandez Milan and Creutzig, 2015; Larsen, 2015; Paz et al., 2016; Liotta et al., 2018; Reckien et al., 2018; Tsiros et al., 2018). Local urban adaptation strategies need to be integrative and address housing and infrastructure, the increase and design of urban green areas, education and awareness-raising of the most vulnerable communities, the implementation of early warning systems for extreme events and the surveillance of climate change induced diseases, the strengthening of local emergency and healthcare services, and the general strengthening adaptive capacity of the community and of the local institutions.

CCP4.4.5 Limits to Adaptation, Equity and Climate Justice

There is *low confidence* that the Mediterranean region can adapt to rapid sea level rise for the case of rapid Antarctic ice-sheets collapse, even in regions with high capabilities to adapt, such as the northwest Mediterranean (Poumadère et al., 2008). Residual coastal risks are still largely unquantified. For moderate levels of sea level rise, it is *unlikely* that these changes alone will exceed the technical limits of coastal adaptation over the 21st century (Hinkel et al., 2018). Beyond 2100, continued sea level rise may require managed retreat in low-lying Mediterranean areas, particularly in delta areas, such as the Nile (Figure CCP4.6). There is little knowledge on the potential for adaptation at these timescales.

Regional adaptation initiatives occur in a highly asymmetric geographic context characterised by contrasting demographic, environmental and socioeconomic trends in the southern, eastern and northern parts of the Mediterranean Basin (Pausas and Fernández-Muñoz, 2012). Adaptation plans in Mediterranean countries are also limited by a lack of effective regional governance schemes (with the partial exception of European countries subject to the European directives and strategies), hampering the effective implementation of regionally harmonised adaptation strategies, plans and quantitative targets (UNEP/MAP, 2016; Sachs et al., 2019). Adaptation to sea level rise is essentially limited by social barriers along urban coasts in the northwest Mediterranean at present (Hinkel et al., 2018), while the adaptation dilemma involving economic and financial barriers is greater in peri-urban, rural and natural areas, as well as in the southern and eastern Mediterranean. In addition, limited regional monitoring of risks and adaptation options hampers adaptation in domains and sectors (Cramer et al., 2018).

In the Mediterranean region, vulnerability is strongly affected by equity: people most vulnerable to the effects of climate change are the elderly, especially women (Iñiguez et al., 2016; Achebak et al., 2018) and children, who are often strongly affected by climate change (Watts et al., 2019). An increase of heat waves poses a significant health risk especially for young children living in urban areas (UNICEF, 2014; Perera, 2017; Royé, 2017) and for elderly women, in particular those affected by other conditions such as respiratory diseases (Sellers, 2016; Achebak et al., 2018). Children and future generations in eastern Mediterranean countries are those most at risk of food insecurity, in both quantity and quality (Prosperi et al., 2014). In the region, many children are particularly vulnerable due to scarcity of drinking water and food, aggravated by droughts and flooding (Philipsborn and Chan, 2018). The potential for adaptation to and preparation for vector-borne diseases and other health risks, expected to increase with climate change, differs among Mediterranean countries (Negev et al., 2015). Climate change in the Mediterranean region also impacts some groups disproportionately (e.g., poor farmers, urban migrants, seasonal workers) and livelihoods (Waha et al., 2017), favouring mobility and migration (Nori and Farinella, 2020).

To safeguard the rights of the most vulnerable people in the Mediterranean region, climate adaptation plans and measures must consider the cost of adaptation (Watts et al., 2019). In addition, some adaptation options can have side and residual effects, favouring some countries/groups over others. Climate-just adaptation options are those that promote fair solutions for all and take into account region-specific socioeconomic and geopolitical variabilities and vulnerabilities, such as the lack of inclusive and participatory approaches (Iglesias and Garrote, 2015) and pre-existing vulnerabilities, as in the case of Palestine (Jarrar, 2015) and Syria (Gleick, 2014).

CCP4.4.6 Pathways for Sustainable Development

Climate-resilient sustainable development pathways are trajectories that combine adaptation and mitigation to realise the goal of sustainable development through iterative, continually evolving socioecological processes (Chapters 1; 18; Denton et al., 2014). Transformative adaptation can be promoted through social and political processes, identifying the enabling conditions and strategies that facilitate structural changes (UNEP/MAP, 2016; Ramieri et al., 2018; EC, 2020; UNEP/MAP and Plan Bleu, 2020). The main options include ongoing structural change in the renewable energy system in this region, the production of renewable biological resources, measures towards increased water irrigation efficiency, behavioural changes in multiple sectors and improved regional governance (Table CCP4.2; Cramer et al., 2018).

There also are risks for nonlinear climate change impacts in key socioeconomic and environmental processes, which could promote reactive changes and forced transformations (Table CCP4.3).

In the Mediterranean Basin, indicators for progress towards the Sustainable Development Goals (SDGs) show multiple directions of transformative change (Sachs et al., 2019). In some sectors, such as energy, there are general positive trends in sustainability (UNEP/MAP, 2016), but there also are significant imbalances between northern and southern shores of the basin for most SDGs. Over the coming decades the Mediterranean Basin will *likely* experience sustained growth in renewable energy investments, accompanied by a shift in regional geographical patterns of energy demand (OME, 2018). However, future developmental pathways, solution space and feasible system transformations could be constrained by multiple factors for several SDGs, such as social conflicts, lack of regional governance, limited action capacity and financial constraints (Figure CCP4.9; Table CCP4.3).

CCP4.4.7 Governance and Finance for Sustainable Development

Several multilateral institutions are managing international environmental governance in the Mediterranean Sea, including, (a) the Barcelona Convention or Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (established under the United Nations Environment Programme, UNEP), (b) the General Fisheries Commission for the Mediterranean (GFCM, a subsidiary of the FAO) and (iii) the Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea (ACCOBAMS, also under UNEP). These institutions act cooperatively pursuing synergies and greater effectiveness (Lacroix, 2016). The Mediterranean Action Plan (MAP) under the Barcelona Convention System involves 21 Mediterranean countries and the EU and promotes the Mediterranean

Table CCP4.2 | Transformative adaptation and mitigation options for climate-resilient sustainable development in the Mediterranean Basin.

Code	Sector	Transformative option	References
T1	Energy, transport and tourism	National plans and regulations to decarbonise fuel sources and electricity grids on the supply side, for reducing energy demand and increasing efficiency and converting transport systems from fossil fuels to electricity.	UNEP/MAP (2016); Bastianin et al. (2017); EEA (2018a; 2018b; 2019); OME (2018); CMI and EC (2019); Sachs et al. (2019); EC (2020); Simionescu et al. (2020)
T2	Energy	Deployment of large-scale Mediterranean transboundary renewable energy infrastructures and interconnections. Transboundary energy market integration schemes.	EIB and IRENA (2015); Tagliapietra (2018); CMI and EC (2019); Zappa et al. (2019); CMI and EC (2020)
T3	Energy	Definition of 'Important Projects of Common European Interest' pooling financial resources and funding large-scale innovation projects across borders in the Mediterranean. Green hydrogen projects in Mediterranean North Africa (especially Morocco) have already been suggested as strategic actions.	CMI and EC (2019; 2020)
T4	Energy – finance	EU Renewable Energy Financing Mechanisms such as calls for proposals for new renewable energy projects, including joint projects with third Mediterranean countries, joint support schemes, innovative technology projects or other projects that contribute to the enabling framework of the Renewable Directive 2018/2001. The mechanism can provide resources from payments by Member States, EU funds (European Green Deal Investment Plan, the Sustainable Finance Strategy, the Just Transition Fund, Connecting Europe Facility) or private sector contributions.	CMI and EC (2019; 2020)
T5	Water	Improving efficiency of irrigation practices, including changing surface water irrigation for other techniques, use of remote sensing in intensive agriculture, optimisation of irrigation practices and other approaches. The Mediterranean region could save 35% of water by implementing improved irrigation techniques.	Iglesias et al. (2011); Boari et al. (2015); Ćosić et al. (2015); Dhehibi et al. (2015); Guilherme et al. (2015); Iglesias and Garrote (2015); Cantore et al. (2016); Fader et al. (2016); Iglesias et al. (2017); Kang et al. (2017); AbdAllah et al. (2018); Iglesias et al. (2018); Malek and Verburg (2018); Vargas and Paneque (2019)
T6	Water	Improvement of water resource availability and quality. Desalinisation and co-generation of electricity and potable water in integrated Concentration Solar Power plants. Reduce climate impacts on nitrate and other pollutant concentrations through improved agriculture and fertilizer management.	Abufayed and El-Ghuel (2001); Elimelech and Phillip (2011); Aguilera et al. (2015); Papanicolas et al. (2016); Bonanos et al. (2017); Cramer et al. (2018); Jones et al. (2019); Lange (2019)
T7	Water	Reduce/control water demand and use through efficiency management and/or modernisation in irrigation.	Sanchis-Ibor et al. (2016); UNEP/MAP (2016)
T8	Water	Water demand management. Behavioural shifts in consumption and diet choice. Diet type influences the amount of water needed to produce and process food. Food waste implies the waste of the water used in the production cycle.	Blas et al. (2016; 2018); Gul et al. (2017)
T9	Water	Adaptation by increasing water trade in international markets (commodity markets).	Antonelli et al. (2012); Hoekstra and Mekonnen (2012); Johansson et al. (2016); Lee et al. (2019)
T10	Food and fisheries	Changing diets, managing food demand and reducing food waste. Reductions in the demand for livestock products.	Bajželj et al. (2014); Havlík et al. (2014); Tilman and Clark (2014); Westhoek et al. (2014); Herrero et al. (2016); van Sluisveld et al. (2016)
T11	Food and fisheries	Shift to more sustainable fishery practices. Collaborative monitoring, research and managing knowledge platforms.	Bjørkan et al. (2020); Raicevich et al. (2020)
T12	Human conflict, displacement, migration and security	Implementation of more effective Mediterranean regional policies and institutional frameworks for human rights protection, management of transboundary human migration, resolution of political and armed conflicts, increased internal displacements and food security.	UNEP/MAP (2016)
T13	Finance	Enhanced Mediterranean transnational governance and financial bilateral and multilateral capacity. Increased finance for regional cooperation and development (above current levels, USD 8300 million yr^{-1}).	UNEP/MAP (2016); Midgley et al. (2018); Fosse et al. (2019)
T14	Coastal	Nature-based solutions aiming at reducing future coastal risks by restoring a buffer zone in coastal areas (e.g., through managed realignment), leaving space for sediments and coastal ecosystems, thus reducing the hazard and exposure to coastal flooding and erosion.	Pranzini et al. (2015)

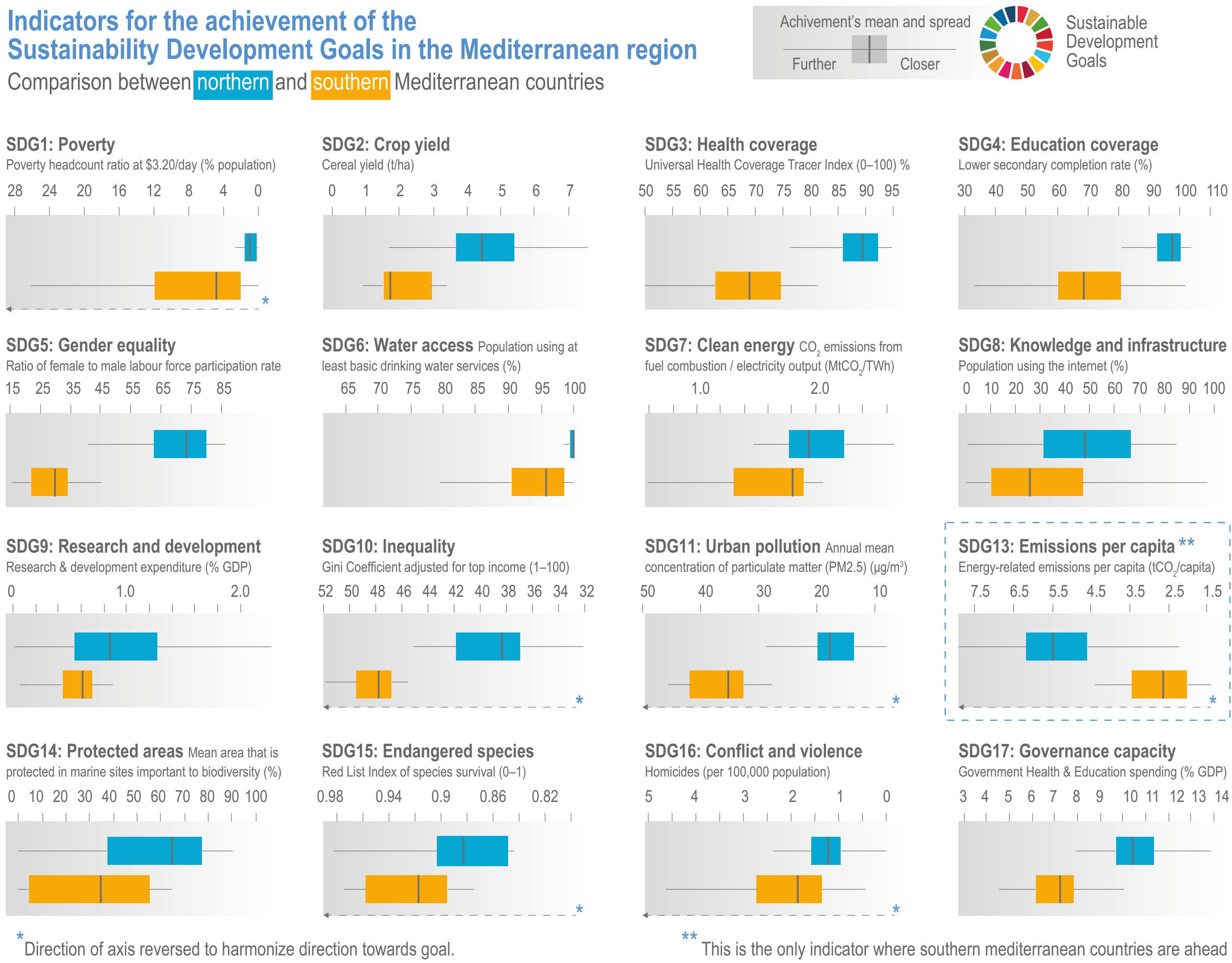

Figure CCP4.9 | Differences in present-day SDG indicator values between northern (blue) and southern (gold) Mediterranean countries. Yellow-shaded areas indicate better indicator values for the SDG descriptor. Red-shaded areas indicate poor performance on SDG values. Details of calculations and indicators in Table SMCCP4.3.

Strategy for Sustainable Development (MSSD), coordinated by the Mediterranean Commission on Sustainable Development (MCSD) (UNEP/MAP, 2016). MAP is primarily financed by national governments and the EU. Its financial capacity for regional environmental governance remains limited, with available annual funds in the range of 5–10 million Euro (Humphrey and Lucas, 2015).

Bilateral public climate finance in the Mediterranean area includes loans by multilateral development banks, bilateral official development aid and international climate fund projects (Midgley et al., 2018; Tagliapietra, 2018). Bilateral public and private financial resources invested in international climate finance in southern Mediterranean countries are two orders of magnitude greater than the existing multilateral regional governance programmes for the environment (EC, 2018; Midgley et al., 2018; Fosse et al., 2019). The MSSD is a tool for enhancing the governance of environmental issues, proposing the biannual reporting by the national parties of a set of quantitative indicators, including the commitments and obligations under the United Nations Framework Convention on Climate Change climate agreement, and other climate change mitigation and adaptation policy actions.

Existing legal and institutional structures can facilitate coordination and collaboration across scales (DeCaro et al., 2017). Legislative mechanisms, such as the rules governing water uses in time of drought, already exist in some Mediterranean countries, but they might not be suitable to cope with irreversible changes (e.g., the depletion of groundwater aquifers) or be flexible enough to respond to the needs of water users under a changing climate (Nanni, 2012). Although legislation can be recognised as a tool in support of adaptive water management, there is a need for better coordination among the various legal provisions that define institutional roles and set out the mechanisms for the management of water resources across different scales (regional/national/sub-national) and sectors (agriculture, industry, urban, energy).

Table CCP4.3 | Nonlinear processes that could force reactive changes and social transformations for climate-resilient sustainable development in the Mediterranean Basin. Nonlinearity implies the absence of a straight-line relationship between the independent variable and the response variable. In other words, changes in the output do not change in direct proportion to changes in the independent variable and the form of the relationship is often described by applying nonlinear mathematical models. Gradual changes induced by climate warming in thermal exposure or rainfall availability can induce nonlinear effects on social and ecological response variables.

Code	Sector	Processes	References
P1	Agriculture and migration	Adverse nonlinear impacts of temperature on agricultural productivity can induce nonlinear effect on human migration. The temperature–migration relationship is nonlinear and resembles the nonlinear temperature–yield relationship. These relationships affect mostly agriculture-dependent countries and especially people in those countries whose livelihoods depend on agriculture.	Reuveny (2007); Schlenker and Roberts (2009); Cai et al. (2016)
P3	All societal sectors	The increase in climatic impacts and catastrophic events is associated with nonlinear changes in economic and social impacts.	Burke et al. (2014); Burke et al. (2015); Carleton and Hsiang (2016); Hsiang et al. (2017); Prahl et al. (2018); Coronese et al. (2019)
P4	All economic sectors	Nonlinear temperature effects on labour conditions.	Burke et al. (2014); Graff Zivin and Neidell (2014); Burke et al. (2015); Somanathan et al. (2018)
P5	All economic sectors	Nonlinear temperature effects on GDP. Higher temperature may reduce GDP in Mediterranean agricultural countries more than non-agricultural countries. Extreme heat over 30°C significantly reduces the GDP of agricultural countries but not the non-agricultural ones. GDP is a main determinant of international migration. The nonlinear relationship between GDP and temperature in agricultural countries provides indirect evidence for the agricultural linkage between temperature and migration.	Dell et al. (2012); Burke et al. (2014; 2015); Cai et al. (2016)
P6	All societal sectors	Nonlinear effects of temperature on human conflict.	Baylis (2015); Burke et al. (2018); Koubi (2018); Baylis (2020)
P7	Food, health and demography	In low-income areas of the Mediterranean Basin and sub-Saharan Africa regions higher poverty rates, malnutrition and elevated infant mortality are coupled with higher fertility, implying a higher rate of population growth that in turn can generate more poverty. These demographic cycles can in turn interact with climatic impacts and conflict-induced displacement and migration processes.	Vörösmarty et al. (2000); Barrios et al. (2006); Reuveny (2007); Hsiang et al. (2013); Ghimire et al. (2015); Brzoska and Fröhlich (2016); Cai et al. (2016); Cattaneo and Peri (2016); Grecequet et al. (2017); Waha et al. (2017); WFP (2017); Livi Bacci (2018); Raineri (2018); Scott et al. (2020)
P8	Energy	Nonlinear effects of increased temperatures on energy demand and supply. High temperatures provoke demand surges while straining supply and transmission.	Carleton and Hsiang (2016)
P9	Industry	Nonlinear effects of temperature on industrial production.	Hsiang and Meng (2015)

Frequently Asked Questions

FAQ CCP4.1 | Is the Mediterranean Basin a 'climate change hotspot'?

Is the Mediterranean 'a geographical area characterised by high vulnerability and exposure to climate change'? Climate change projections for the Mediterranean Basin indicate with very high consistency that the region will experience higher temperatures, less rainfall and continued sea level rise during the coming decades. Given that summers are already comparatively dry, these factors together will likely cause substantially drier and hotter conditions as well as coastal flooding, impacting people directly but also harming ecosystems on land and in the ocean.

For the Mediterranean Basin, climate models consistently project regional warming at rates about 20% above global means and reduced rainfall (–12% for global warming of 3°C). While it is not the region with the highest rate of expected warming on Earth, the Mediterranean Basin is considered particular in comparison to most other regions due to the high exposure and vulnerability of human societies and ecosystems to these changes: a 'climate change hotspot'.

Rising temperatures trigger extensive evaporation of water from all wet surfaces, notably the sea, lakes and rivers, but also from soils. Along with decreasing rainfall, this evaporation leads to shrinking water resources on land, drier soils, reduced river flow, and significantly longer and more intensive drought spells. Since the Mediterranean climate is already relatively dry and warm in the summer, any additional drought (and also heat) will affect plants, animals and people significantly, and ultimately entire societies and economies.

In general, increasing temperatures and more intensive heat waves in the basin threaten human well-being, economic activities, and also many ecosystems on land and in the ocean. Extreme rainfall events, which despite the

FAQ CCP4.1(continued)

lower total rainfall are expected to increase in intensity and frequency in some regions, generate significant risks for infrastructure and people through flash floods. Warming also affects the ocean and its ecosystems, jointly with acidification caused by atmospheric carbon dioxide. Finally, sea level rise, currently accelerating because of global ice loss, threatens coastal ecosystems, historical sites and a growing human population.

Key risks in the Mediterranean and their location for SSP5-RCP8.5 by 2100

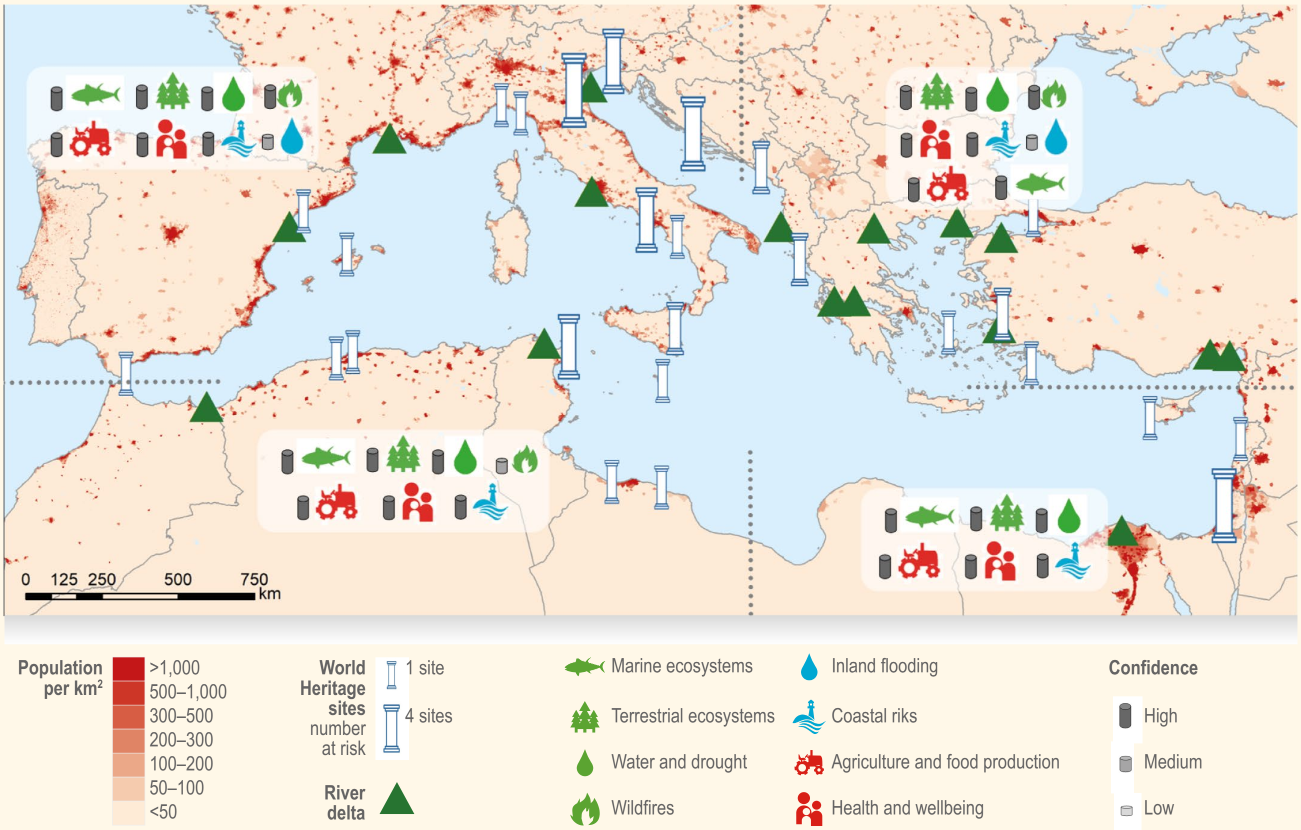

Figure FAQ CCP4.1.1 | Key risks across the Mediterranean region by 2100. The symbols above the map highlight risks enhanced by climate change which apply to the entire region with *high confidence*. Other risks are localised in the map.

Risks associated with projected climate change are particularly high for people and ecosystems in the Mediterranean Basin due to the unique combination of many factors, including:

- A large and growing urban population exposed to heat waves, with limited access to air conditioning
- A large and growing number of people living in settlements impacted by rising sea level
- Important and increasing water shortages, already experienced by 180 million people today
- Growing demand for water by agriculture for on irrigation
- High economic dependency on tourism, which is likely to suffer from increasing heat but also from the consequences of international emission reduction policies on aviation and cruise-ship travel
- Loss of ecosystems in the ocean, wetlands, rivers and also uplands, many of which are already endangered by unsustainable practices (e.g., overfishing, land use change).

Frequently Asked Questions

FAQ CCP4.2 | Can Mediterranean countries adapt to sea level rise?

The rates of observed and projected sea level rise in the Mediterranean are similar to the Northeast Atlantic, potentially reaching 1.1 metres at the end of the present century. Erosion, flooding and the impacts of salinisation are projected to be particularly severe due to the special conditions of the coastal zones in the region. Beyond a few tens of centimetres, adaptation to sea level rise will require very large investments and may be impossible in some regions.

Sea level in the Mediterranean has been rising by only 1.4 mm yr^{-1} during the 20th century, more recently by 2.4±0.5 mm yr^{-1} from 1993 to 2012, and it is bound to continue rising in the future. Future rates are projected to be similar to the global mean (within an uncertainty of 10–20 cm), potentially reaching 1.1 m or more around 2100 in the event of 3°C of global warming (Figure FAQ CCP4.2; Table SMCCP4.4). Due to the ongoing ice loss in Greenland and Antarctica, this trend is expected to continue in coming centuries. Sea level rise already impacts extreme coastal waters around the Mediterranean and it is projected to increase coastal flooding, erosion and salinisation risks. These impacts would affect agriculture, fisheries and aquaculture, urban development, port operations, tourism, cultural sites and many coastal ecosystems.

Most of the Mediterranean Sea is a micro-tidal environment, which means that the difference between regular high and mean water levels (astronomical tides) is very small. Storm surges and waves can produce coastal floods that persist for several hours, causing particularly large impacts on sandy coasts and eventually also on coastal infrastructure. Mediterranean coasts are also characterised by narrow sandy beaches that are highly valuable for coastal ecosystems and tourism. These beaches are projected to be increasingly affected by erosion and eventually disappear where sedimentary stocks are small.

Overall, Mediterranean low-lying areas of significant width occur along 37% of the coastline and currently host 42 million inhabitants. The coastal population growth projected until 2050 mostly occurs in southern Mediterranean countries, with Egypt, Libya, Morocco and Tunisia being the most exposed countries to future sea level rise. The area at risk also hosts 49 cultural World Heritage sites, including the city of Venice and the early Christian monuments of Ravenna. The Mediterranean also includes areas subjected to sinking of the land (subsidence), including the eastern Nile Delta (Egypt) and the Thessaloniki flood plain (Greece), where local relative sea level rise can exceed 10 mm yr^{-1} today.

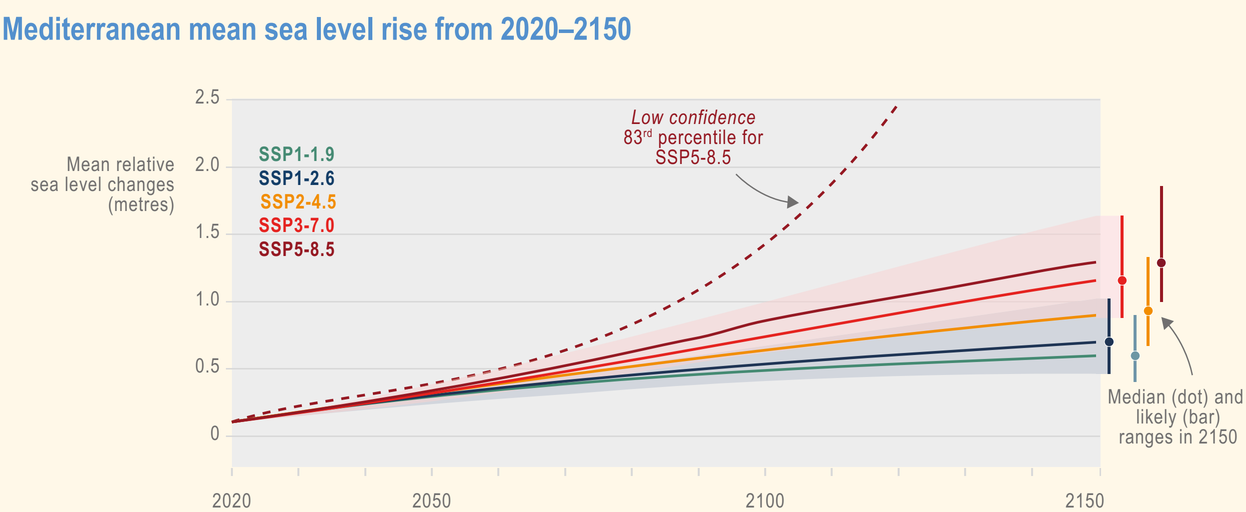

Figure FAQ CCP4.2.1 | Mediterranean Sea level projections. These projections translate the global estimates in WGI AR6 Chapter 9 to the Mediterranean Basin (Fox-Kemper et al., 2021). They assume that sea level change in the Mediterranean continues to be forced by Atlantic Sea level change seen at the Gibraltar Strait (Section CCP4.1) and thus follow the global mean beyond 2100. Vertical ground motions induced by glacial isostatic adjustments are also included, but not those due to other natural or anthropogenic processes such as tectonics or groundwater extractions. Intra-basin sea level changes are not included. Data available as supplementary material.

FAQ CCP4.2 (continued)

Adaptation to sea level rise in the Mediterranean includes engineering or soft/ecosystem-based protection, accommodation, and retreat or managed realignment. Despite various limitations, adaptation already happens today to some extent, as for example the coastal flood and erosion protections along the subsiding Nile Delta coast. Only massive coastal protection and other sustainable development policies could reduce the growing number of people exposed to sea level rise by 20%. It appears therefore *likely* that the number of people exposed could increase by up to 130% by 2100.

Without drastic mitigation of climate change, sea level rise is projected to accelerate and will require additional coastal engineering protection projects (e.g., dykes or groynes). Despite their efficiency for the few next decades, these engineering options have also adverse impacts for coastal ecosystems and may not ensure that the recreative value of Mediterranean coasts can be sustained (see Box 13.1 on Venice on the movable barriers protecting the Venice Lagoon). Among nature-based solutions, there are immediate benefits of restoring dunes and coastal wetlands to restore a buffer zone between coastal infrastructure and the sea and therefore reduce coastal risks (Cross-Chapter Box SLR in Chapter 3). Yet, this kind of protection is not feasible everywhere, particularly in urbanised areas, where it faces its limits. The limits for adaptation in the Mediterranean to further acceleration of sea level rise have stimulated ideas of large-scale geoengineering projects such as surface height control dams at Gibraltar. However, such projects come with unknown risks for humans and ecosystems.

Frequently Asked Questions

FAQ CCP4.3 | What is the link between climate change and human migration in the Mediterranean Basin?

Climate change already influences conflict and migrations occurring within countries or regions. However, climate is only one of the multiple factors affecting conflict and migration decisions across countries and regions. It is currently not possible to attribute particular conflicts or migrations to climate change and also in the future migration will most likely depend on the economic, social and governance context.

The Mediterranean Sea is the world's most dangerous place for migrants, with more than 20,000 deaths reported since 2014. Although empirical evidence indicates that migration related to climate impacts is mostly internal to national borders, climate change is likely to contribute to migration in the Mediterranean Basin as one out of several factors. Climate impacts contribute to migration flows particularly by affecting the economic and political drivers of migration.

Many migrants attempting to cross the Mediterranean to Europe originate from sub-Saharan Africa, a region heavily affected by climate change. In West Africa, for example, migration decisions are heavily influenced by perceptions of climate change and of its economic impact on resources and income. However, projections are uncertain, because climate impacts in Africa might both increase human suffering and thus enhance mobility, but they could also limit mobility of people through lack of financial resources.

The impacts of climate change on conflicts and security are increasingly documented, especially in Africa. Climate impacts may not in itself have caused social and political unrest but can contribute to them. The conflict in Syria has occurred after the drought that marred the country in the years before, but there is no evidence for direct causal linkage. There is, however, high agreement that food insecurity and land degradation, which can be induced by climate change, are major drivers of political upheavals and instability in northern and sub-Saharan Africa.

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