Threats to human life and livelihoods from environmental change

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Chapter 3

Threats to human life and livelihoods from environmental change

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Executive summary

Water: Water scarcity is a prevailing condition in many Mediterranean countries, while ongoing and anticipated changes in climate conditions are likely to exacerbate this challenge. The western and central Mediterranean countries are characterised by markedly higher water availability than in the southern and eastern parts of the Basin where water for agriculture is the dominant consumer of available water (up to around 80%). The Mediterranean region has become highly urbanised, and urban structures face particularly severe challenges including increased warming compared to surrounding rural areas caused by the 'heat island effect' and increased demand for potable water for human consumption and the upkeep of green spaces in cities. Effective adaptation measures at the local to regional level are necessary to address these difficulties and lower the likelihood of local communities being forced to migrate *(medium to high confidence)*. {3.1}

Food: Environmental change will induce adverse impacts on the agriculture and fisheries sectors. This will mainly be caused by longer-lasting and increasingly intense marine and terrestrial heat waves, as well as droughts and floods on land (*medium* to *high confidence*). These impacts will *likely* involve reduced farm and fisheries productivity and, in combination with non-climatic drivers of change, an exacerbation of risks to food security (domino effect). These trends apply to the entire Mediterranean Basin, with greatest challenges foreseen for southern and eastern Mediterranean countries *(high confidence).* {3.2}

Health: Conflicts and human migration, driven by a combination of climate-related and non-climate related factors, have significant implications for public health in the Mediterranean Basin. Conflicts beyond the Mediterranean region (i.e. Ukraine) can have indirect consequences for the health of Mediterranean populations, for example with regard to the provision of food or other essential daily life items. People living in conflict zones in the Mediterranean (such as Gaza or Syria), as well as refugees and immigrants arriving at their destination in Mediterranean countries from inside and outside the Mediterranean, experience disproportionately high rates of poverty and endure inadequate living conditions. This includes substandard housing, contaminated water, and insufficient healthcare facilities. Such poor conditions result in risks to human health and represent hotspots for outbreaks of infectious diseases. People living in conflict zones, as well as refugees and migrants, are also vulnerable to poorer mental health. The treatment of mental illnesses among both adult and child refugees, together with child malnutrition, are frequently neglected. The elderly, the chronically ill, people who work outdoors, and those from low-income backgrounds are particularly susceptible. {3.3}

Coasts: Sea level rise will increase the frequency and intensity of already existing coastal hazards such as flooding due to extreme sea levels, beach erosion and saltwater intrusion into soils and aquifers *(high confidence).* The impacts of these hazards will be exacerbated by future socio-economic developments in the coastal zone (e.g. population growth or decline, urbanisation levels and expansion, asset and critical infrastructure development) *(high confidence).* {3.4}

Ecosystems: The Mediterranean's terrestrial, marine, and freshwater ecosystems are predicted to be adversely affected by environmental change. Forests are expected to experience increased drought, heat stress, wildfires, and pest vulnerability, while forecasts for freshwater ecosystems suggest that they will encounter declining water availability and the drying out of lakes. In marine ecosystems, increased sea-surface temperatures are likely to affect plankton availability and favour the occurrence of tropical invasive species, hence disrupting food chains. These impacts will be exacerbated by additional anthropogenic activities, including intensive agriculture, industrial development, and fisheries exploitation. Provisioning ecosystem services, including those associated with timber and non-timber forest products and fisheries, will decline. These trends have the potential to result in displacement, as communities may need to seek alternative livelihood opportunities (*medium* to *high confidence*). {3.5}

Energy: Extreme weather conditions affect conventional energy production operations such as coal mining and oil and natural gas exploitation.

Power plants may need to be modified to run at lower temperatures with lower efficiency if they rely on water bodies for their cooling needs. Extreme weather conditions also alter and affect the renewable energy production of solar photovoltaic systems, wind turbines, hydroelectric plants, and biomass production. Transportation networks, including those for electricity and conventional fuels, are expected to be impacted by climate change. Rising temperatures and erratic wind patterns are a clear threat to overhead cables and pylons used in the transmission of power. Environmental change will therefore have an impact on living conditions at the local to regional level, potentially resulting in decreased energy security for the vast majority of local populations due to increased needs for space cooling or devastating storm events. {3.6}

Interactions between sectors: Several sectors (i.e. water, food, health, coasts, ecosystems and energy) are affected by both environmental changes and socio-economic changes across the Mediterranean region *(high confidence)*. The impacts on these sectors are highly interconnected *(Figure 3.11)*, therefore resulting in compounding stresses on human livelihoods. The interaction of impacts across sectors, and their compounding effects, may potentially trigger conflict and migration across the region *(medium confidence)*. {3.7}

Introduction

The overall aim of *Chapter 3* is to provide an overview of the impact of environmental change, including climatic drivers (e.g. extreme precipitation, heat waves, sea level rise) and non-climatic drivers that are not directly related to climate change (e.g. overfishing, pollution, dams, urbanisation, governance challenges), on a range of sectors that may endanger human life and livelihoods and cause conflict and/or migration. The findings for the sectors considered build on the main results of the First Mediterranean Assessment Report (MedECC 2020) *(Figure 3.1)*. *Sections 3.1–3.6* therefore discuss the impacts of environmental change on the respective sectors, how non-climatic factors exacerbate the pressures caused by environmental change, and the potential effect of these developments on conflict and migration. Whenever possible, each section additionally covers a number of cross-cutting themes, such as differences in urban versus rural areas, the interaction of climatic and non-climatic drivers in worsening environmental stresses, as well as regional differences across the Mediterranean Basin. *Section 3.7* summarises and examines interconnections among all sectors in light of their potentially magnifying implications for migration and conflict.

3.1 Water

3.1.1 Introduction

Large parts of the Mediterranean have long struggled with water scarcity, but resourceful local populations have found innovative ways to efficiently manage this scarce resource. The amount of precipitation for a given region depends on ever-changing climate conditions and the occurrence of extreme events. Since the industrial revolution in the late 19th century, changes in climatic conditions have resulted in significant warming, clearly impacting water availability in the Mediterranean Basin. Looking at the recent past, *Figure 3.2* presents the spatial distribution of mean annual precipitation values based on CRU TS[45] gridded datasets (Climatic Research Unit gridded Time Series, Harris et al. 2014) for 1951–2009. It can be clearly seen that annual precipitation values for southern and eastern parts of the region amount to less than 800 mm yr^{-1}, while the values for the northern part of the region lie mainly below 1000 mm yr^{-1} (Philandras et al. 2011). The trend for the number of rainy days for the period 1951–2010 is decreasing for the western and central Mediterranean and slightly increasing for the eastern Mediterranean (Philandras et al. 2011).

The mean total annual renewable water availability per person amounts to 629 m^3 capita^{-1} yr^{-1} for the MENA region, a value well below the water stress limit of 1000 m^3 capita^{-1} yr^{-1} (Table 1 in Lange 2023). However, there is significant geographical variation between individual countries, with western and central parts of the Basin characterised by markedly higher values than those in the southern and eastern parts *(Figure 3.3)*.

The rise in annual mean temperatures in the Mediterranean has already reached the 1.5°C level since the pre-industrial era (Cramer et al. 2018; *Chapter 2, Section 2.4*). Moreover, the frequency and intensity of extreme events (heat waves, droughts, heavy rainfall) have also markedly increased over the last few decades and are expected to continue to rise (e.g. Perkins-Kirkpatrick and Lewis 2020; Zittis et al. 2021). All these observations demonstrate a pronounced drying trend throughout the Mediterranean, with a particular emphasis on and increase in the risk of higher water scarcity in the eastern and southern parts of the region (see *Figure 2.8* in Cherif et al. 2020). While not explicitly covered here, changes in environmental conditions, for example industrial pollution or the use of fertilisers and pesticides and their effects on surface and groundwater quality also significantly affect water availability.

3.1.2 Current state of water availability and spatial distribution

In most Mediterranean countries, agriculture is the dominant consumer of available water. On average, 64% is used for irrigation, 11% for domestic use, and 25% for industry in the Mediterranean (Blinda

[45] CRU TS series of data sets (CRU TS = Climatic Research Unit Time Series) contain gridded monthly fields of precipitation, daily maximum and minimum temperatures, cloud cover, and other variables covering Earth's land areas: https://crudata.uea.ac.uk/cru/data/hrg/

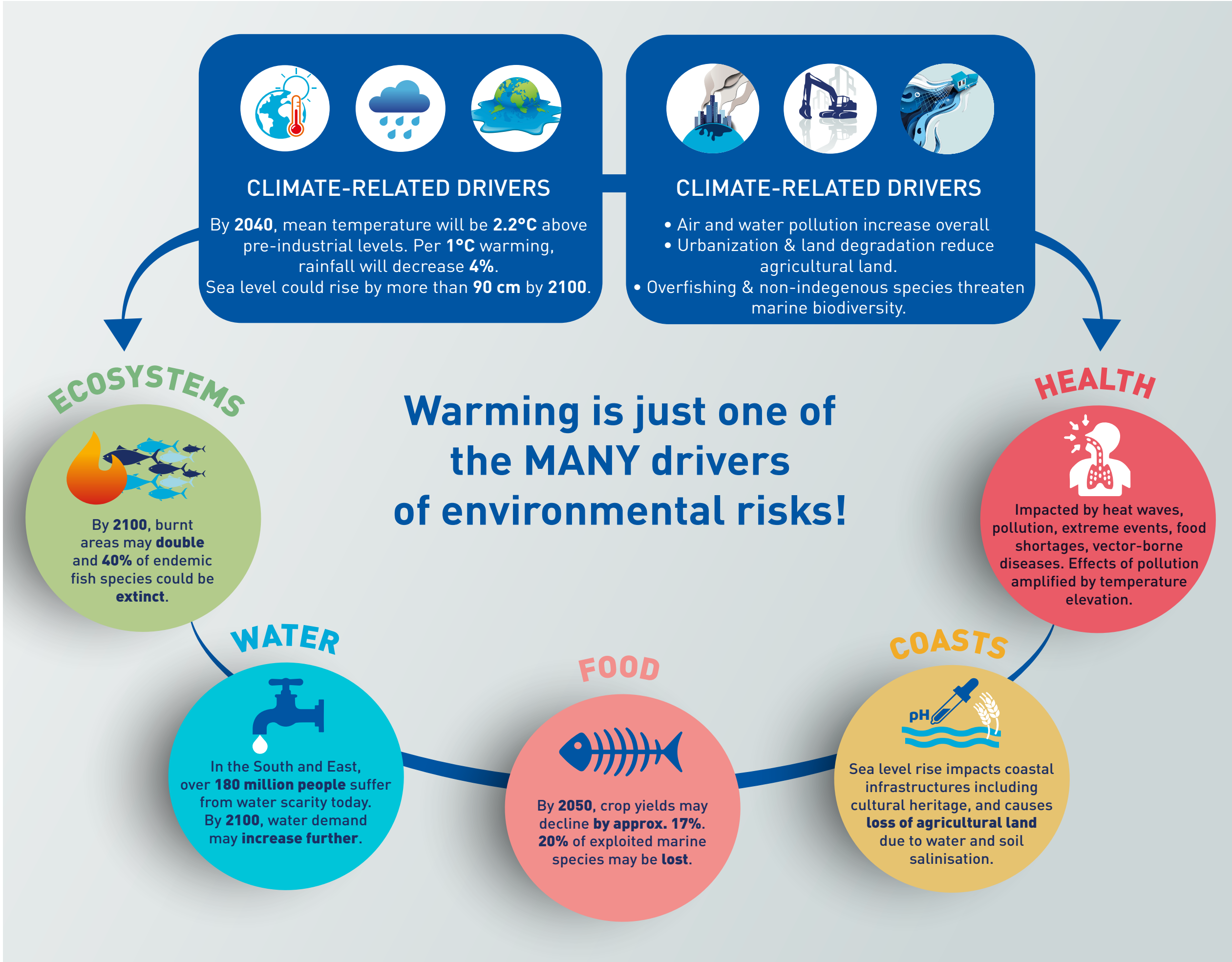


Figure 3.1 | **Infographic summarising the main results of the First Mediterranean Assessment Report (MAR1) published in 2020.** Source: MedECC (2020).

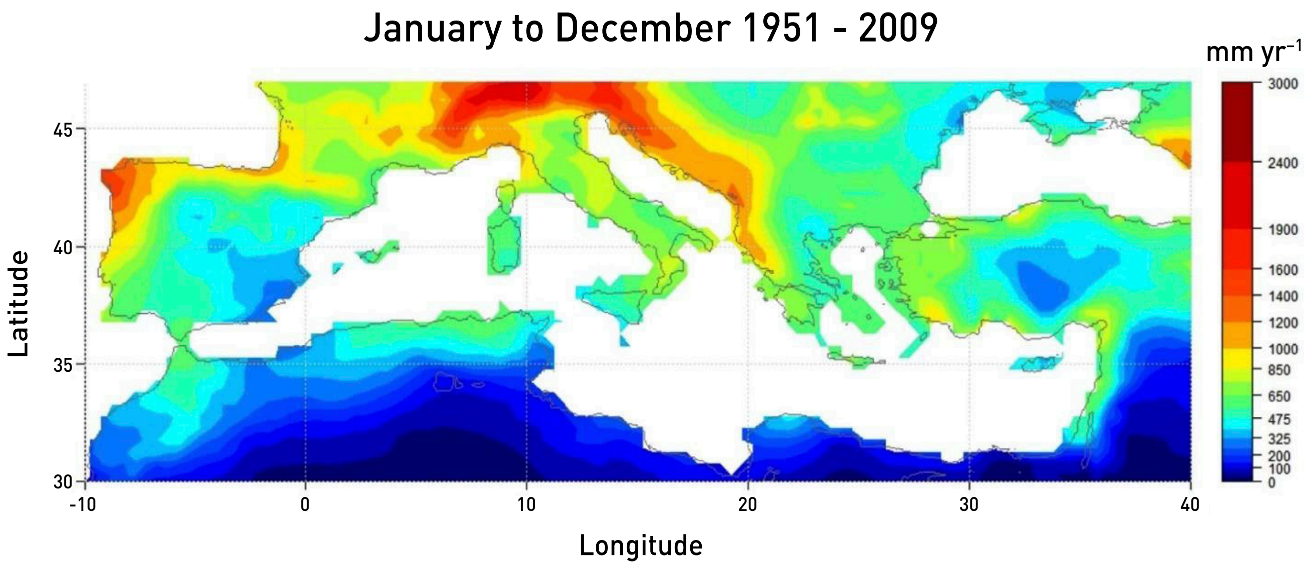


Figure 3.2 | **Spatial distribution of mean annual precipitation values based on CRU gridded datasets.** Source: Philandras et al. (2011).

2008; Mandi 2014; Fader et al. 2020; García-Vila et al. 2024). The Mediterranean Basin's available water resources of between 1060 $km^3 yr^{-1}$ and 1452 $km^3 yr^{-1}$ are unevenly distributed, with the northern countries holding 72 to 84%, while the eastern and southern countries receive the remaining 16 to 28% of the available water (EC 2007; Ferragina 2010). There is therefore a great deal of variation between Mediterranean sub-regions regarding the proportion of water consumed by various sectors *(Table 3.1)*.

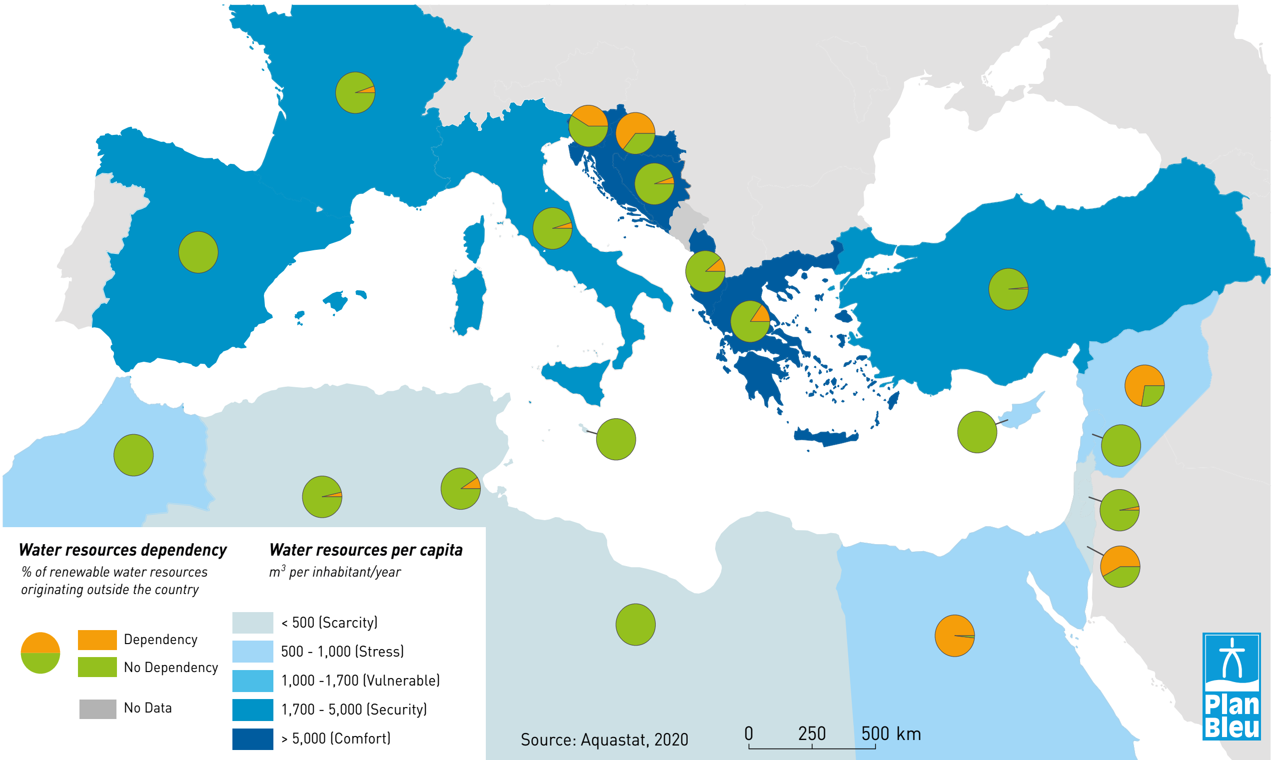


Figure 3.3 | Total renewable water resources per capita in the Mediterranean in 2017. Source: UNEP/MAP and Plan Bleu (2020).

Table 3.1 | Distribution of water use for individual sectors and sub-regions of the Mediterranean Basin. Source: Fader et al. (2020).

Mediterranean sub-region	Water use for sector, %		
	Agriculture	Industry	Domestic
Northern Mediterranean	36	48	16
Southern Mediterranean	76	20	4
Eastern Mediterranean	79	6	13

Given anticipated changes in climate up to the end of the century, reduced precipitation and extreme events (e.g. extended dry spells) will increase the risks of severe water scarcity (see *Figures 2.10* and *2.11* in Cherif et al. 2020) in large parts of the Mediterranean Basin, transforming it into a global 'drought hotspot' (Spinoni et al. 2020).

A decrease in the water available for irrigation will have direct consequences for agricultural productivity and food security in some Mediterranean countries. It will also reduce the amount of environmental water, that is water needed to maintain healthy terrestrial ecosystems, and may lead to accelerated desertification in semi-arid and arid parts of the Basin. Both impacts will likely enhance pressure on local communities and may lead to forced mobility within and beyond national borders.

The Mediterranean is characterised by a high degree of urbanisation (e.g. Lange 2019), which is likely to increase over the next few decades. As a result of climate change, cities will suffer significantly enhanced warming compared to the surrounding countryside, caused by the 'heat island effect' (for more details, see Lange 2019). The resulting extreme conditions will not only affect human health and the indoor comfort of the urban population; they will also lead to rising demand for potable water and for water to maintain cities' green spaces. Extreme heat will also require increased space cooling in public and private buildings. Both issues will increase water and energy needs in the context of the water-energy nexus (Lange 2019, 2022). Growing pressure on urban inhabitants may also give rise to increased migration away from the unbearably hot conditions of cities in the Mediterranean.

3.1.3 Human pressures and water management

The consequences of ongoing climate change and increasing water scarcity described above increase the pressure to develop effective adaptation strategies at the local to regional level. Water management in several Mediterranean countries is characterised by low efficiency and the decentralisation of responsibilities to various governmental institutions. Demand side management and the provision of incentives to reduce consumption are largely missing. In addition, many urban distribution networks are plagued by significant leakage problems (ageing and the use of steel pipes), which reduce available potable water for city inhabitants.

Although technically feasible, advanced irrigation technologies combined with smart agricultural practices are still only rarely implemented in many Mediterranean countries. Moreover, the choice of crops and fruits cultivated in a given country should be adjusted to reduce agricultural water needs and minimise the inappropriate export of virtual water[46] to other countries.

There is an urgent need to effectively adapt to the expected increase in water scarcity, particularly in the southern and eastern countries of the Mediterranean Basin, in order to reduce the risk of further forced migration of local communities (more details on effective mitigation and adaptation strategies are provided in Lange 2019, 2022). Given the prospect of continued decreases in precipitation, alternative water sources will have to be utilised. Seawater desalination, already practised in some Mediterranean countries (e.g. in Algeria, Cyprus, Greece) and likely to be introduced in others, is only an option of limited viability. This is mainly because of the significant energy demand of desalination, and the resultant relatively high cost of desalinated water. Using renewable energy sources offers promising alternatives to provide the energy needed for desalination. Given the conditions in the southern and eastern parts of the Mediterranean Basin, solar or wind energy, or a hybrid solution involving both (or more) renewable energies are therefore feasible alternatives to using ground- and surface water under enhanced climate change-induced water scarcity.

[46] The term 'virtual water' refers to the water consumed at every step in a value chain of a given good, service or process. This water must therefore be 'expended' to grow fruits or vegetables throughout the entire production process (see Graham et al. (2020)).

3.2 Food

3.2.1 Historical and projected impacts of environmental changes on agriculture and fisheries sectors in the Mediterranean

Recent temperature increases and enhanced dry periods in the Mediterranean region have been most severe in the summer months, a crucial phenological stage for crops, with implications for agricultural production (Vogel et al. 2021). Examples of impacts identified include significant yield losses for wheat (up to –20% in Italy) and barley throughout the period between 1989 and 2009 (Moore and Lobell 2015). The livestock sector has also been adversely affected by increased thermal stress, especially within intensive, indoor production systems more prevalent in the northern Mediterranean. Indirect effects include land degradation (e.g. in the Algerian steppes, see Mouhous 2005), reduced grassland productivity, limited water availability, and increased occurrence of pathogens and vectors (Lacetera et al. 2013; Blanco-Penedo et al. 2020). Past evidence throughout the region shows a link between an increase in temperature and the temperature-humidity index and increased mortality rates among dairy cows and sheep (Vitali et al. 2009), alongside declines in milk quality (Blanco-Penedo et al. 2020) and yields (Ramón et al. 2016; Hempel et al. 2019).

The Mediterranean Basin has been identified as a climate change 'hotspot' (see Cherif et al. 2020; Lionello and Scarascia 2020; Ali et al. 2022), with future climate change projections indicating continued intensification of warming under a range of emissions scenarios. By 2100, 4°C warming has been projected to result in severe drought-induced economic losses throughout Europe, particularly in the Mediterranean agricultural sector — potentially reducing its economic output by 10% (Naumann et al. 2021). In general, the greatest yield reductions are forecast for the southern Mediterranean. This will have particularly severe consequences for agricultural employment, which suffers from limited adaptive capacity (Aguilera et al. 2020). Crop growth models and land suitability studies have been carried out for a number of regionally important products. The lowest yield reductions are foreseen for maize (Olesen et al. 2011), especially in comparison to winter wheat, which will primarily be affected in rain-fed areas (Moriondo et al. 2011; Saadi et al. 2015; Schilling et al. 2020). Significant Mediterranean-wide reductions in sunflower yields have also been forecast due to the crop's exposure to hot summer months, where the greatest increases in extremes are anticipated (Moriondo et al. 2011; Cramer et al. 2018; Abd-Elmabod et al. 2020). Rain-fed tomatoes and horticultural crops are furthermore expected to be adversely impacted (Saadi et al. 2015; Aguilera et al. 2020). Declines in productivity are also expected for (rain-fed) olive and grapevines, not only as a result of increases in heat stress and drought but also from additional extremes, notably heavy rainfall, frost, and hail (Olesen et al. 2011; Tanasijevic et al. 2014; Aguilera et al. 2020). For grapevines, these changes are reported to exacerbate adverse impacts on product quality (Ferrise et al. 2013; Cramer et al. 2018). Northern Mediterranean regions are on the other hand projected to see an increase in suitability for a number of crops, including winter wheat, tomatoes, and olives (Saadi et al. 2015; Aguilera et al. 2020, García-Vila et al. 2024).

Attribution studies indicate that anthropogenic climate change has increased the frequency and intensity of extreme heat wave events in the Mediterranean. In addition to enhanced heat stress, increases in extreme rainfall events and the risk of wildfires (Clarke et al. 2022) are *likely*. The 2003 summer heat wave contributed to an increase in fire risk and the occurrence of mega-fires in France and Portugal. The severity of these events was significantly higher than previously observed, as fire conditions in France had formerly been observed at a probability of occurrence of less than 0.2% (Barbero et al. 2020; Clarke et al. 2022). There is evidence of direct adverse impacts of wildfires on agricultural production in the Mediterranean region in recent years, as witnessed in affected coastal agricultural lands in Greece in 2004–2005 (Stougiannidou and Zafeiriou 2022). However, more indirect effects have also been reported, such as reduced grape quality from wildfire smoke exposure in Italy (Brunori et al. 2021). Flooding has also caused adverse impacts on the agricultural sector (e.g. Gil-Guirado et al. 2019), including livestock mortality and failed harvests (especially in conjunction with landslides; Amengual and Borga 2020). Additionally, waterlogging from flooding has reduced plant growth and yields, particularly in sensitive crops such as olives and avocados (Kourgialas 2021).

Infrastructure has also suffered from climate change impacts, particularly with regard to irrigation, drainage systems, and soil conservation structures, resulting in increasing vulnerabilities of the agricultural sector to concurrent drought risk, as evidenced in Tunisia (Dahri and Abida 2020).

The spread of invasive agricultural weeds, pests and diseases is furthermore affected by climate change (e.g. through the spread of the olive fruit fly; Skuras and Psaltopoulos 2012; Ponti et al. 2014). Impacts on livestock vary distinctly between mixed production systems (primarily characterising the northern basin), where farmers benefit from production diversification, and open rangelands or industrial livestock systems (Cramer et al. 2018). Projections for the bovine sector include increased losses in monthly income throughout summer months because of changes to temperature and humidity (Hempel et al. 2019), and declines in milk productivity (Lacetera et al. 2013), potentially increasing reliance on imports (Sraïri et al. 2013).

An additional impact of major concern to food production is sea level rise (*Section 3.4.1*) — particularly in the Nile Delta, where 25% of the land area lies at or below current sea levels, and where fertile agricultural areas are at risk of flooding and saltwater intrusion (Zittis et al. 2022).

The fisheries sector has been impacted by rising temperatures and more extreme summer heat waves. Mass mortalities first identified throughout the 1980s have since become a recurring feature, and were particularly severe in 1999, 2003, and 2008 (Darmaraki et al. 2019; Garrabou et al. 2019). Climate change projections point towards an increase in the severity of marine heat waves (i.e. with regard to duration and intensity) in the Mediterranean Sea under mid- and high-end climate change scenarios (RCP4.5 and RCP8.5; *Section 3.5.1*). These events are forecast to become up to 42 times more severe than at present (Darmaraki et al. 2019). Opportunities for species to adapt by moving to higher latitudes are limited within the semi-enclosed Mediterranean Sea (Ben Rais Lasram et al. 2010; Albouy et al. 2012), and the region, like most of the world, is projected to see a further decline in catches and fisheries revenues (Lam et al. 2016). By 2050, more than 20% of exploited fish and marine invertebrates are forecast to become extinct in the region (Cramer et al. 2018).

3.2.2 Beyond direct impacts: indirect environmental effects and consequences

A number of additional processes are resulting in increased pressure and/or the deterioration of scarce resources in the Mediterranean region. These may either be independent from, or indirectly driven or exacerbated by climate change. Across the Middle East and North Africa, population numbers are expected to exceed 1 billion by the end of the century (Zittis et al. 2022), with smaller increases projected for northern and eastern Mediterranean countries (Malek et al. 2018). This trend, alongside tourism development, is intensifying pressure on freshwater resources (Zittis et al. 2022) and is further driving the urbanisation of coastal areas and the sealing and loss of agricultural land, with important implications for flood risk (Malek et al. 2018; Tramblay et al. 2019; Ferreira et al. 2022). Further concerns involve regional land degradation. Across Europe, the highest rates of soil erosion and loss of soil organic matter are found in Mediterranean countries (Ferreira et al. 2022). In Slovenia, 41% of agricultural land is estimated to be severely eroded, resulting in high economic losses associated with foregone yields, a trend that is also pronounced in Spain, Italy, and Greece (Panagos et al. 2018; Ferreira et al. 2022). Erosion is primarily driven by agricultural intensification — a process that is also driving the loss of organic matter (e.g. via intensive tillage), as well as soil pollution (e.g. nitrate contamination from livestock production, or pollution from excessive use of fertilisers and fungicides; Ferreira et al. 2022). In Morocco and Tunisia, land degradation is estimated to result in a 0.5% decrease in Gross Domestic Product. Additional soil degradation issues are associated with salinisation, exacerbated by groundwater abstraction, affecting crop yields (Ferreira et al. 2022). In Egypt, 90% of agricultural land is affected by salinisation and waterlogging (FAO and ITPS 2015).

The Mediterranean Sea is furthermore at risk of pollution from coastal activities (as it is home to numerous refineries and chemical plants), seaborne traffic, and (micro)plastics (Trincardi et al. 2023). Furthermore, few areas within the Mediterranean Sea are considered to represent sustainable fisheries, with the Adriatic Sea showing the highest levels of exploitation of commercial species and the EU Mediterranean displaying declining landings and overall negative economic trends (Colloca et al. 2017). These trends are furthermore hampered by an increase in invasive species favoured by warming conditions, particularly in the eastern Mediterranean Sea and in connection with the Suez Canal (Cramer et al. 2018).

3.2.3 Implications for livelihoods, migration, and conflict

Other impacts of adverse environmental changes include limited capacities for adaptation. This explains the high spatial variability in climate risk assessment for fisheries throughout the

Figure 3.4 | Climate risk assessment for fisheries in the Mediterranean Basin. Source: Pita et al. (2021).

Mediterranean Basin, with countries in North Africa displaying the highest risk scores (Pita et al. 2021) *(Figure 3.4).* Marine Protected Areas have been identified as an effective means of increasing fish biomass within rocky reefs of the Mediterranean Sea, but they need to take into account future changes in climatic gradients to ensure long-term conservation (Frid et al. 2023). The Mediterranean region has also seen an increase in aquaculture production, mitigating some of the declines in fisheries landings (Hilmi et al. 2021).

Uneven adaptation capacities have similarly been identified for Mediterranean croplands, with areas of greatest exposure to increased drought and heat stress also displaying lower adaptation potential (Zagaria et al. 2023). Core adaptation enablers have been identified as greater market accessibility and water/irrigation availability, higher land ownership rates, lower poverty levels, and suitable soil and slope conditions for resilient crop production (Zagaria et al. 2023).

Varying degrees of climate risk within the agriculture and fisheries sectors imply varying degrees of impact on Mediterranean livelihoods which, to a significant extent, are dependent on the type of environmental impact experienced. Sudden onset events (e.g. storms, floods) limit the potential for reactive adaptation and may result in immediate destructive outcomes through loss of land and infrastructure. They are therefore more likely to cause a loss of livelihoods, employment, and food security within subsistence agricultural households. These impacts are more often associated with temporary and short-distance forms of migration. With regard to slower-onset environmental change processes (including drought and land degradation from erosion and increased salinity), impacts on yields, produce quality, and fisheries landings are more often gradual. In these situations, migration is more likely to be identified as a 'voluntary' adaptation strategy – despite the limited potential for other forms of adaptation (MedECC 2020a). In such cases, the motivations for migration are primarily perceived as economic, and often occur along a rural-urban gradient (e.g. Fernández et al. 2019; Sobczak-Szelc and Fekih 2020), associated with an increase in poverty and a decrease in employment linked to declining suitability of farming and fishing. Environmental change may therefore be interpreted as an important intermediary or secondary factor for migration (Cai et al. 2016). This is particularly the case in contexts of pre-existing vulnerability (Fargues et al. 2020; Cundill et al. 2021) where food insecurity is one of several contributors to political instability (Ali et al. 2022).

3.3 Health

3.3.1 Interconnections between conflict, human migration and environmental change, and impacts on public health

Public health, environmental change, conflict, and associated displacement and involuntary migration are all interrelated. Environmental changes have a profound direct impact on public health and also generate and exacerbate political conflicts and human migration. Migrants and refugees, in particular, face significant risks to their health and well-being, as they constitute a vulnerable population that is disproportionately impacted by conflicts (Matlin et al. 2018; Negev et al. 2019). Within the Mediterranean Basin, and mainly in the southern and eastern countries, factors such as severe drought, water shortages, and pollution *(Section 3.1),* food insecurity *(Section 3.2),* lack of adaptive capacity, and increased climatic risks all intensify political conflicts and aggravate regional disputes (Gleick 2014; Al-Delaimy 2020; Paz et al. 2021). Furthermore, extreme weather events and sea level rise *(Section 3.4)* force inhabitants to migrate (see *Section 5.1.4* regarding the climate-mobility association). Conflicts and migration therefore serve as determinants of both physical and mental illness.

Immigrants and refugees experience disproportionately high rates of poverty and endure inadequate living conditions, including substandard housing, contaminated water, and insufficient healthcare facilities. The precarious conditions along migration routes, at destinations, and in refugee camps, along with environmental degradation such as land erosion, food insecurity, and water pollution, as well as climate change-induced events like extreme heat waves, cold spells, wildfires, and droughts, increase the vulnerability of immigrant populations. These conditions heighten the risk of malnutrition, infectious diseases, heat- and cold-related morbidity and mortality, and mental health disorders, including post-traumatic stress disorder, depression, anxiety, and physical injuries during migration or in unsafe camps (Berry et al. 2018; Hayes et al. 2018; Bellizzi et al. 2020). Migration also leads to short- or long-term lack of access to essential determinants of health, including education, job security, and social networks. This exacerbates poverty, social stratification, social isolation, and loneliness among migrants.

Additionally, limited access to healthcare services poses a significant challenge for the health of migrants, with national or local health systems often ill-equipped to address these needs (Paz et al. 2021). In destination countries, refugees and immigrants typically have limited access to healthcare services, primarily relying on emergency care and immunisations, along with maternal and child preventive care. Healthcare coverage is largely inadequate, and language barriers and cultural differences further complicate access to healthcare, leading to a deterioration in health. Moreover, the treatment of mental illnesses among both adults and children is frequently neglected, despite poor mental health increasingly becoming a significant health consequence of environmental change, conflict, and migration (Al-Delaimy 2020).

3.3.2 Current and future health pressures caused by environmental change, migration, and conflict in the Mediterranean

The relationship between low socio-economic development, environmental change, conflict, and their impact on public health is complex and multidimensional. Climate change is a factor that can contribute to the risk of armed conflicts within countries. However, in general, its influence is relatively low compared to other drivers, and the mechanisms linking climate to conflicts remain uncertain (Mach et al. 2019).

Conflicts and human migration, driven by various combinations of climate-related and non-climate related factors, have significant implications for public health in the Mediterranean Basin. The influence of climate change relative to other factors is debated in the literature. For example, studies on the Syrian war showed that environmental change, including the most severe recorded drought (Kelley et al. 2015), persistent multi-year crop failures, and associated economic deterioration, all played an important role in contributing to political instability in Syria. This in turn led to displacement of people, food insecurity, higher unemployment, and increased violence (Gleick 2014; Kelley et al. 2015; Lal 2021). On the other hand, Selby et al. (2017) argued that the evidence linking environmental change to the conflict in Syria is unreliable, and that the scale of the migration caused by the drought was small. According to their study, migration was caused more by economic liberalisation than by the prevailing drought.

Migration itself poses various health risks influenced by a complex interplay of factors, including an individual's pre-departure health, socio-economic and environmental conditions, local disease patterns, risk behaviours, cultural norms, and access to preventive or curative therapies throughout the migration process (Abubakar et al. 2018). Migrant populations often bear a significant burden of diseases such as tuberculosis, hepatitis B and C, and vaccine-preventable illnesses (Vearey et al. 2020). Despite the recognition of the many migration-related health risks, mobile populations often encounter punitive border policies, arbitrary detention, abuse, extortion, and limited access to healthcare services (Abubakar et al. 2018). For instance, in Greece, poor living conditions, communication difficulties, exclusion from services, and instances of racism and xenophobia have detrimental effects on the health of asylum seekers, refugees, and immigrants (Fouskas et al. 2019).

Furthermore, conflicts beyond the Mediterranean region can have indirect consequences on the health of Mediterranean populations. For example, the war in Ukraine led to a surge in wheat prices, potentially affecting food security and nutrition in Mediterranean countries heavily reliant on imported wheat, such as Egypt, which imports 82% of its wheat from Russia and Ukraine (FAS USDA 2022).

Environmental changes in the Mediterranean also affect human health through changes in the dispersion pathways of atmospheric pollutants and the concentrations of particulate matter (PM). Particulate matter originates primarily from Saharan dust intrusions and advected smoke from wildfires (Linares et al. 2020). The human health effects of dust storms range from respiratory disorders (such as asthma, pneumonia, and allergic rhinitis) to cardiovascular disorders (including strokes), conjunctivitis, skin irritations, and injuries related to transport accidents (Goudie 2014). Health risks associated with wildfires include direct risks from exposure to fires, as well as risks from heavy wildfire smoke (Xu et al. 2020). Indeed, alongside the increasing frequency and extent of wildfires, especially in the European parts of the Mediterranean region (Peñuelas et al. 2017), an increase in PM10 concentrations in the eastern Mediterranean is linked to dust storms, which are *likely* attributed to changes in synoptic-scale conditions driven by climate (Krasnov et al. 2016).

Additional health and environmental emergencies also pose a risk to human health in the Mediterranean. In late 2019, COVID-19, the illness caused by SARS-CoV-2, emerged and spread very quickly across the globe, with 760 million cases and a death toll of nearly 7 million people (WHO 2023). Mediterranean countries experienced varied impacts, resulting in different durations and stringencies of lockdowns and public health restrictions. Italy was the first country in the region to report a major outbreak, with over 35,000 deaths in 2020 and more than 100,000 cumulative deaths by early 2021 during another major wave of infections. Multiple waves occurred in Spain as well, while Greece reported fewer total fatalities.[47] In less developed Mediterranean countries (i.e. Algeria and Egypt) the spread of COVID-19 exposed gaps in epidemic preparedness and health system capacity (Paz et al. 2021).

On 4 August 2020, a large explosion occurred at the port of Beirut, Lebanon, caused by the detonation of approximately 2750 tons of improperly stored ammonium nitrate. The explosion resulted in over 200 fatalities, and injured around 6000 people, with approximatively 300,000 individuals temporarily displaced, with severe impacts on their health. The disaster also rendered three hospitals non-functional, severely damaged two others, and destroyed 17 containers of essential medical supplies (Devi 2020).

Health service delivery in armed conflict areas faces multiple challenges. For example, in Syria, health services have been heavily disrupted as a result of the crisis, while attacks have left health centres damaged and, in some cases, non-functional, significantly reducing access to essential health services for affected populations (Bozo et al. 2019). This complex situation increases the risk of common infectious diseases, which are highly sensitive to climate variability, as warmer temperatures and altered rainfall patterns can create more hospitable environments for both vectors and pathogens (Hess et al. 2020). Vector-, food-, and water-borne diseases tend to be more prevalent in vulnerable areas, including some developing countries within the Mediterranean region, where exposure risks are amplified by factors such as poor sanitation and inadequate infrastructure. Poor conditions such as

[47] European Centre for Disease Prevention and Control (ECDC): https://www.ecdc.europa.eu/en/covid-19/data

those in refugee camps and in high density cities with poor water infrastructure, whether due to low socio-economic status or conflict, may contribute to increasing the density of infectious agents and reduced disease control (WHO 2018). Migration driven by climate change may increase the incidence of communicable diseases among both migrants and host populations, and increase the rate of non-communicable diseases in the migrant population (Spearman et al. 2023). An alarming example is the increase in cutaneous leishmaniasis (CL) by tens of thousands of cases in Syria in early 2013, in places that are not historical hotspots of CL, a change that might be attributed to the massive human displacement within Syria. Additionally, CL has begun to emerge in neighbouring countries (Jordan, Lebanon, and Türkiye), where displaced Syrians and disease reservoirs coexist, in parallel with ecological disruption of sandfly habitats (Al-Salem et al. 2016). In September 2022, the UN warned that a cholera outbreak in Syria, which has not reported cholera since 2009, poses a 'serious threat' to the region, with more than 1000 suspected cases and eight reported deaths, while the true numbers are likely to be under-reported. The outbreak's source was thought to be unsafe water from the Euphrates River used for drinking and to irrigate crops, leading to food contamination.

The civil war has damaged two-thirds of Syrian water treatment plants, half of its pumping stations, and a third of its water towers. Almost half of the population relies on alternative sources of water, such as water trucks, which are often unsafe, while at least 70% of sewage is untreated. Currently, the UN estimates that 14.6 million people in Syria need humanitarian assistance, half a million children are chronically malnourished, and many health facilities remain damaged amid a severe shortage of health professionals (Devi 2022).

Poor water quantity and quality in refugee camps in Algeria, including onsite health institutions, is another example of microbiological contamination and consequential health risks. In Egypt, Saad-Hussein et al. (2014) suggested that bilharzial cancer cases were emerging among farmers displaced from their agricultural land due to sea level rise.

In addition to water insecurity, migrants and refugees are at risk of food insecurity. Despite governmental and international efforts, refugees face limited access to adequate food in terms of quantity, quality, and diversity (Vakos et al. 2021). In addition, severe personal identity traumas such as physical and sexual violence against women, have been observed among Syrian refugees, while the rate of post-traumatic stress disorder (PTSD) and depression have also been high (Al Ibraheem et al. 2017). In Gaza, the continuous conflict with Israel, comprising strict siege conditions and destruction of infrastructure, together with poor health infrastructure, a high urbanisation rate, and low socio-economic status, exacerbated by climate change, rising temperatures, and lack of safe water, all lead to deteriorating physical and mental health (Efron et al. 2018).

Special attention should be paid to the child population. In Türkiye, the country hosting the largest number of Syrian refugees in the world (3.6 million), 46% of them are under the age of 18. These children face a variety of risks to their health and well-being, including communicable and non-communicable diseases, PTSD, depression, and family violence, as well as child labour and child marriage. It was found that malnutrition is a key issue for Syrian refugee children, and it is more prevalent compared to Turkish children (Sahin et al. 2021). Environmental stressors also contribute to the migration from Africa to Europe, across the Mediterranean Sea. Between 2015 and 2023, every year thousands of people were defined as 'dead' or 'missing' with the lowest number (1510) in 2019 and the highest (5096) in 2016[48]. In 2023, 35,200 refugee and migrant children arrived in Bulgaria, Cyprus, Greece, Italy, Malta, and Spain, via sea and land, mainly from the eastern, central, and western Mediterranean and North Africa, 41% more than the total number in 2021. Of these, 67% were unaccompanied or separated from both their parents. Health systems should address the effects of environmental change on migration and health, including early warning systems, vaccination programmes, capacity building of healthcare professionals, and protection of migration corridors and displaced people (Spearman et al. 2023).

3.3.3. Intersectional vulnerability

While environmental change, conflict, and migration have adverse impacts on the physical, mental, and social health of the general public, certain population groups are even more vulnerable. This includes the

[48] UNHCR Operational Data Portal, Europe Sea Arrivals: https://data.unhcr.org/en/situations/mediterranean

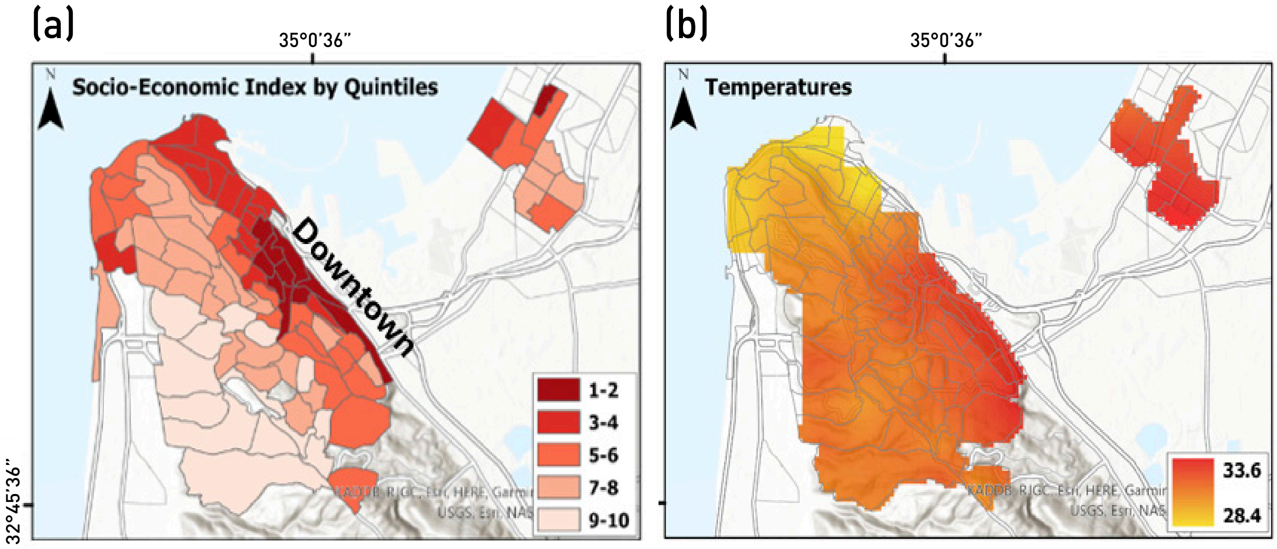


Figure 3.5 | Intersectional vulnerability and exposure in the Mediterranean city of Haifa (Israel). (a) Socio-economic status and (b) Average temperature on excessively hot days in August between 2010 and 2019. The downtown population is subject to intersecting vulnerabilities and exposure – belonging to the lowest socio-economic quintile and living in the hottest area in summer. Source: Negev et al. (2022).

elderly, the chronically ill, women, children, people who work outdoors, and economically deprived populations, including those suffering from energy, food, or water poverty. In addition, those who suffer intersectional vulnerability (people who encounter vulnerability in two or more dimensions — that is, the elderly who are chronically ill, or women who are economically deprived) and/or are exposed to intersectoral stressors, are disproportionately vulnerable (IPCC 2022). For example, city-dwellers may be more exposed to heat stress due to the urban heat island effect. Urban structures are warmer (and more polluted) than surrounding rural areas. Moreover, certain areas within cities may be exposed to even higher heat stress due to urban morphology, including a high density of buildings, vegetation, land cover, land use, etc. (Ellena et al. 2020). Urban temperatures are unequally distributed within cities. For example, a study conducted in Cairo, Egypt, showed that people in marginalised, informal districts are highly exposed to heat and less capable of protecting themselves, putting their health at increased risk (Khalil et al. 2018). Another study conducted in Haifa, Israel, showed that the lowest socio-economic neighbourhoods (Socio-Economic Index <2) are also the most exposed to high temperatures in summer *(Figure 3.5)* (Negev et al. 2022). People with intersectional social vulnerability who are also more exposed to environmental stressors are therefore facing higher health risks than others, and are often less able to adapt to environmental change than other groups of inhabitants.

3.4 Coasts

3.4.1 Impacts of environmental change

The mean sea level of the Mediterranean Sea has, on average, risen by 1.4±0.2 mm yr^{-1} during the 20th century (Wöppelmann and Marcos 2012). This rate increased to 2.4±0.5 mm yr^{-1} for 1993 to 2012 (Bonaduce et al. 2016). By the end of the 21st century, mean sea level will increase by between 0.43 m and 0.87 m relative to 1995–2014, depending on the greenhouse gas emission scenario considered (*Figure 3.6*; Ali et al. 2022). Impacts of relative mean sea level variations comprise submersion and permanent coastline retreat; seawater intrusion into freshwater aquifers; higher groundwater tables; and degradation of marine ecosystems. These impacts constitute a major threat to coastal communities, not only with regard to the near-coastal ecosystem, but also because of adverse consequences on coastal infrastructure and economic activities in coastal regions (Oppenheimer et al. 2019).

To compensate for current rainfall scarcity, groundwater has been extensively used for agricultural irrigation in the Mediterranean (Nixon et al. 2003). Groundwater aquifers are at risk due to low recharge because of projected decreasing precipitation volumes, rising temperatures and increased water demand. Consequently, seawater intrusion is of particular concern in the Mediterranean region, since a significant proportion of agricultural land is located along the coast. Many coastal aquifers already suffer from seawater intrusion (Mas-Pla et al. 2014; Telahigue et al. 2020), and this is projected to increase in the future. Although mean sea level rise has a lower impact on groundwater salinity than groundwater recharge reduction, it can still worsen seawater intrusion (Pisinaras et al. 2021). In the Nile Delta, a 1 m rise in mean sea level would result in a 15% reduction in fresh groundwater (Sefelnasr and Sherif 2014). In the Po Delta, rising sea levels and decreasing river discharge could cause an increase of up to 80% in seawater intrusion by the end of the 21st century (Bellafiore et al. 2021).

Delta systems are low-elevation land areas that support substantial socio-economic activities. Subsidence rates in the larger Mediterranean deltas range between 1.4 and 10 mm yr^{-1} (Stanley 1997; Besset et al. 2017; Belivermis et al. 2024). An example is the Ebro Delta, where 73% of permanent land loss is expected under a relative mean sea level rise of 0.67 m, resulting from the RCP8.5 emission scenario (van Vuuren et al. 2014) by the end of the century (Sayol and Marcos 2018). Subsidence also affects cities in the Mediterranean, exacerbating the exposure of coastal populations to flooding. Groundwater abstraction in the Po Delta has accelerated the natural long-term subsidence in the Venice lagoon, contributing to about half of the historical relative mean sea level rise in Venice (Zanchettin et al. 2021). The city of Alexandria is subsiding due to its location in the Nile Delta, at a rate of up to 2 mm yr^{-1} (Wöppelmann et al. 2013), and has therefore been considered one of the most exposed cities to coastal flooding.

In addition to mean sea level, changes in other components of sea levels (astronomical tides, waves, storm surges) exacerbate coastal erosion and flooding. Extreme waves and surges will exacerbate erosion and flood risks along the coast, as mean sea level defines the baseline level from which extreme events propagate. Extending the example above, the 73% land loss in the Ebro Delta will increase to between 89.4% and 90.5% when accounting for extreme waves and surges (Sayol and Marcos 2018). Mean sea level rise and extreme sea levels will further exacerbate ongoing beach retreat (Enríquez et al. 2017, 2019; Belivermis et al. 2024). Nearly 50% of the sandy coastline in the Mediterranean and Black Sea regions experienced erosion between 1980 and 2000 (www.eurosion.org; Marcos et al. 2016). Mean sea level rise is estimated to result in an average beach loss of 65.5% on 869 beaches in the Balearic Islands by the end of the century, increasing to 86.3% during a storm event (Agulles et al. 2021). Similar results have been obtained for Greece (Tzoraki et al. 2018; Andreadis et al. 2021) and, although site-specific studies are required, analogous outcomes are anticipated in other Mediterranean coastal zones. These coastal changes are of particular significance considering that beaches serve as vital natural barriers for coastal protection against marine storms and are also significant contributors to the region's sun-and-beach tourism industry (Enríquez and Bujosa Bestard 2020).

3.4.2 Current and future socio-economic pressures

The consequences of environmental changes on human lives and livelihoods in coastal areas, in particular those caused by sea level rise, are largely driven by socio-economic developments in the Mediterranean coastal zone. Historically, settlements have developed in the direct coastal zone due to the low tidal range and steep topography in the adjacent hinterland (Benoit and Comeau 2005; UNEP/MAP 2017; Lange et al. 2020). Ancient civilisations therefore developed in the region, and

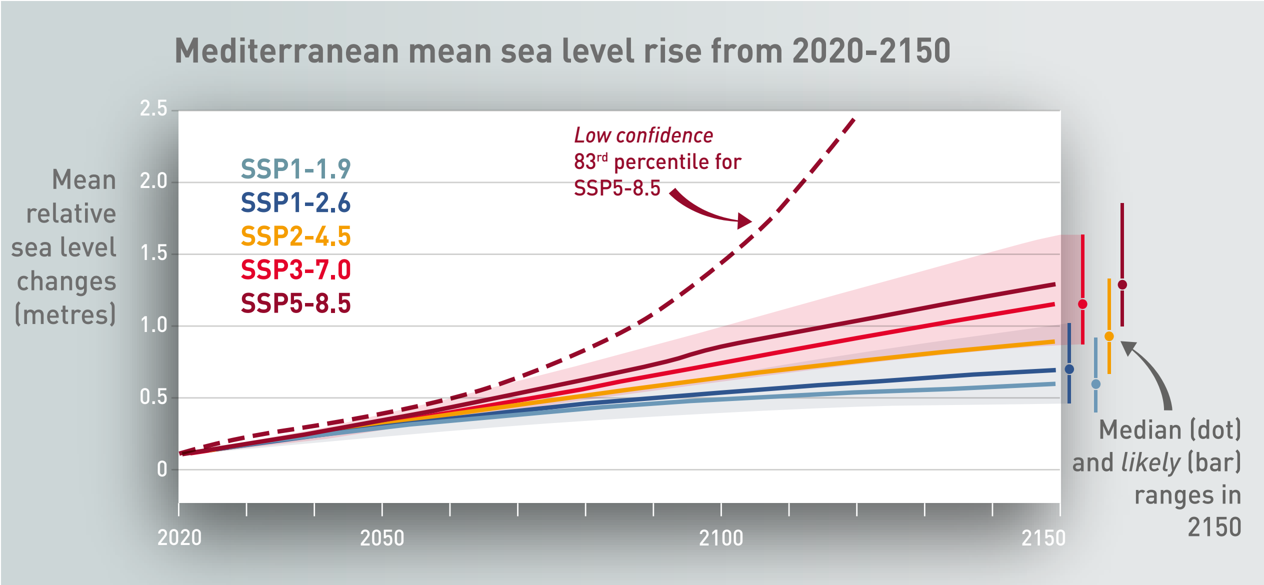


Figure 3.6 | Mean sea level rise projections for the Mediterranean Sea and six climate scenarios and the *likely* range. Source: Ali et al. (2022).

their remnants are now often listed on UNESCO's World Heritage list, with a high concentration of UNESCO World Heritage sites located in the immediate coastal zone (Cazenave 2014; Reimann et al. 2018b). Similarly, the Mediterranean coastal zone is densely populated, with almost one third of the total Mediterranean population (roughly 150 million people) living within 20 km of the coast, and approximately 10% (about 47 million) in the Low Elevation Coastal Zone (LECZ)[49] in 2010 (Reimann et al. 2021). Further, slightly more than half of the population in the LECZ lives in urban areas; however, these patterns differ considerably between Northern Mediterranean countries[50] (~77% urban) and Southern and Eastern Mediterranean countries[51] (~43% urban) (Reimann et al. 2021). Infrastructure such as ports, roads, and railways are therefore also concentrated in coastal locations (Piante and Ody 2015; Lagarias and Stratigea 2022).

The Mediterranean coastal zone has experienced rapid socio-economic growth in recent decades (EEA 2006; EEA and UNEP/MAP 2014; Piante and Ody 2015). This has been driven by the shipping, fishing and tourism industries, but also by lifestyle choices, with a high share of second home ownership in the region (Reimann et al. 2018a). With progressing urbanisation and continued attractiveness of the coastal zone for human settlements, the LECZ population is expected to grow between 10% (SSP4) and 130% (SSP3) by 2100 (compared to 2010), depending on the socio-economic scenario (Shared Socioeconomic Pathway, SSP; *Box 1*) (Reimann et al. 2021). However, if stringent coastal zone management is pursued, the LECZ population may decrease by 18% by 2100 (SSP1) (Reimann et al. 2018a). Future coastal population growth will differ substantially between the northern Mediterranean and southern and eastern Mediterranean countries *(Figure 3.7a)*, with an increase compared to 2010 in the LECZ population in the southern and eastern parts by 100 million under all SSPs. Furthermore, a large proportion of the future coastal population is expected to live in urban areas, with a substantial increase projected in the southern and eastern countries over the course of the 21st

[49] The LECZ covers all land up to 10 m elevation in hydrological connection to the sea (McGranahan et al. 2007; MacManus et al. 2021).

[50] Andorra, Croatia, Cyprus, France, Greece, Italy, Malta, Monaco, San Marino, Slovenia, Spain, the Vatican.

[51] Algeria, Albania, Bosnia and Herzegovina, Egypt, Israel, Lebanon, Libya, Montenegro, Morocco, Palestine, Syria, Tunisia, Türkiye.

century *(Figure 3.7b)* (Reimann et al. 2021). Moreover, urban areas are expected to undergo considerable expansion between 2012 and 2100. According to various urban development projections, the urban footprint in low-lying coastal areas (below 20 m) is expected to increase significantly, ranging from 67% for Italy to 104% for the Mediterranean coast of France (Wolff et al. 2020).

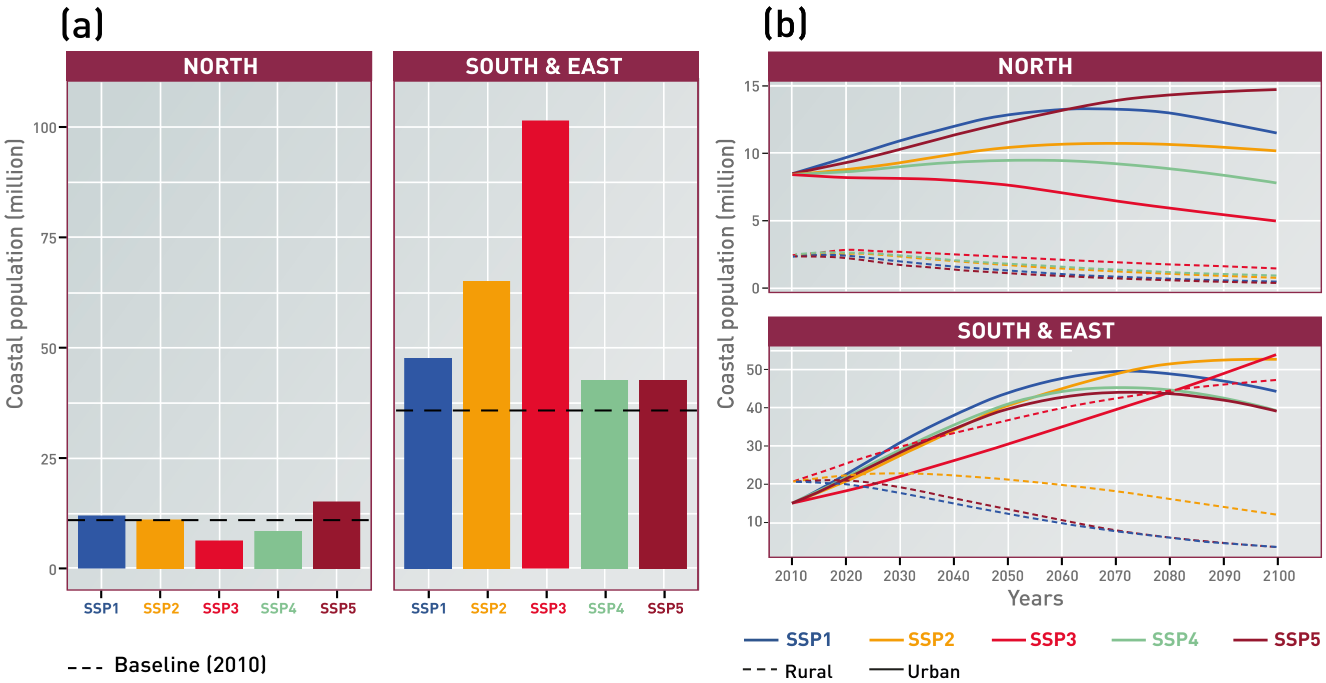


Figure 3.7 | Population in Low Elevation Coastal Zone (LECZ) by geographical region and Shared Socioeconomic Pathways (SSPs). (a) Population in 2100 relative to 2010; (b) Urban and rural population changes from 2010 to 2100. Figure adapted with minor adjustments from Reimann et al. (2021).

Box 3.1

The Shared Socioeconomic Pathways (SSPs)

The Shared Socioeconomic Pathways (SSPs) are one component of the current scenario framework in climate change research, which consists of climate scenarios (Representative Concentration Pathways, RCPs), socio-economic scenarios (SSPs), and climate policy scenarios (Shared Policy Assumptions, SPAs) (van Vuuren et al. 2014; O'Neill et al. 2020).

Five SSPs describe plausible alternative trends in global-scale societal development in the course of the 21st century based on their socio-economic challenges for climate change mitigation and adaptation (O'Neill et al. 2014). Each SSP has an underlying narrative that qualitatively describes a broad range of socio-economic developments in the form of a storyline (O'Neill et al. 2017). In SSP1, challenges are low as society develops sustainably; in SSP2, historic patterns in socio-economic development continue, leading to moderate challenges; SSP3 has high challenges due to resurgent nationalism and limited global cooperation; SSP4 has high adaptation challenges as inequalities are high within and across countries; and SSP5 is characterised by rapid economic growth based on fossil fuels, which leads to high challenges for mitigation *(Figure 3.8)*.

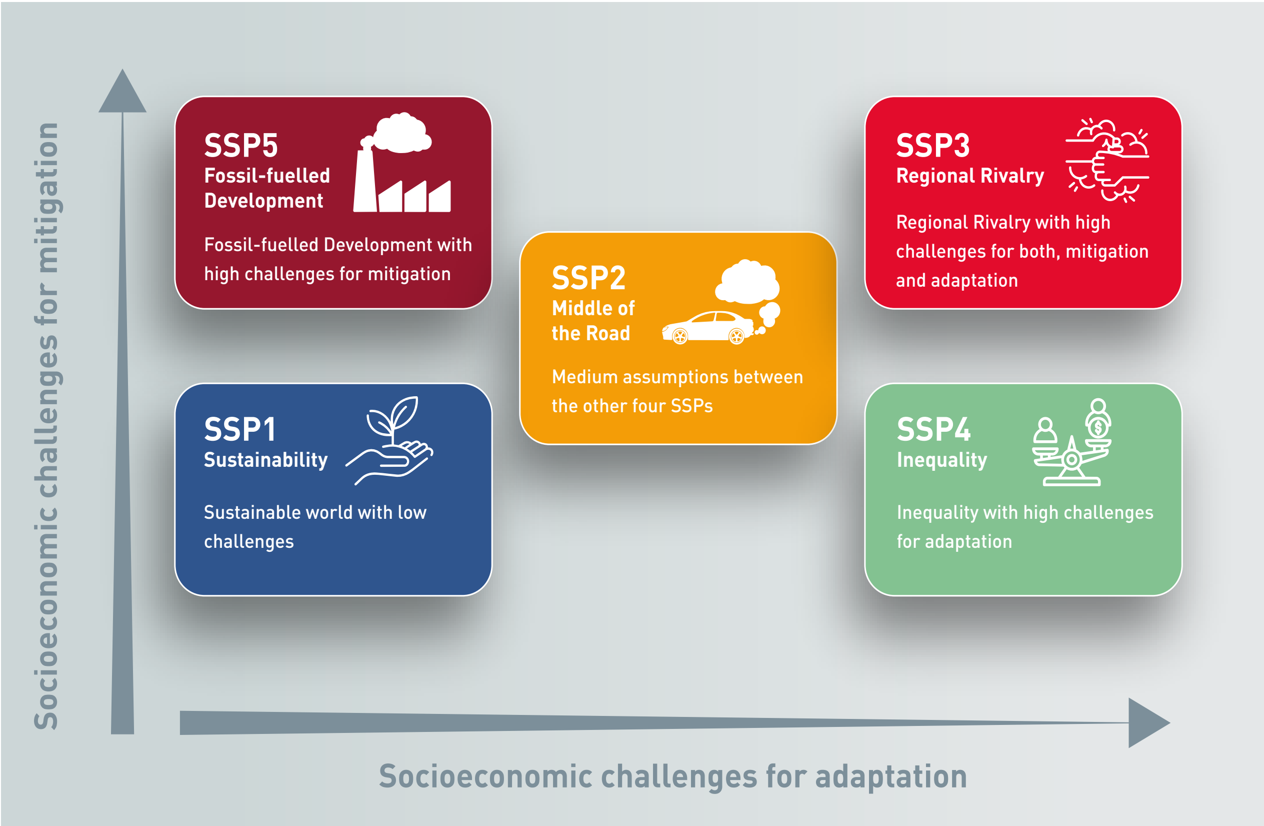


Figure 3.8 | Socio-economic challenges for climate change adaptation and mitigation. Figure modified from Reimann et al. (2023b).

3.4.3 Implications for conflict and migration

Socio-economic development will be a major driver of environmental change impacts on lives and livelihoods in coastal locations in the future (Reimann et al. 2023b), but current knowledge of this kind of feedback is still too limited. A recent study projects up to 20 million internal migrants by 2100 due to sea level rise if no adaptation strategies are implemented (Reimann et al. 2023a). In particular in the arid southern parts of the Mediterranean region, habitability is expected to decrease, putting pressure on population and settlements from two sides: the coast (due to sea level rise) and inland areas (due to desertification) (Reimann et al. 2018a; Clement et al. 2021). Furthermore, coastal flooding due to extreme sea levels may result in loss of life, temporary displacement, and permanent migration away from the coast as flooding becomes more frequent and intense, for example threatening the livelihoods of people due to a reduction in agricultural yields through saltwater intrusion *(Section 3.4.1)*. While few settlements will be directly threatened by progressing coastal erosion, coastal residents recognise the impact of coastal erosion on their daily lives and understand the anthropogenic causes of coastal erosion problems including change impacts (Tourlioti et al. 2021). Coastal erosion will *likely* have a considerable effect on the attractiveness of Mediterranean beaches for tourism purposes. Currently, about 80% of regional employment is directly related to the tourism sector (Manca and Santarossa 2016) and annual tourist arrivals are currently increasing, especially in North Africa and Europe (Mejjad et al. 2022).

Environmental change impacts on lives and livelihoods such as the examples discussed above are further exacerbated by considerable differences in governance and adaptive capacity across northern, eastern, and southern parts of the region (EEA and UNEP/MAP 2014; UNEP/MAP 2016; Cramer et al. 2018). While coastal adaptation planning is part of the Mediterranean Action Plan and the Integrated

Coastal Zone Management (ICZM) protocol in the Mediterranean[52], implementation has so far been limited and fragmented across the region, leaving poorer population groups vulnerable to climate change impacts in coastal areas, especially in the southern and eastern Mediterranean (Cramer et al. 2018). Future socio-economic development in the 21st century (i.e. SSPs) will considerably influence adaptation practices and coastal management. However, adaptive capacity is *likely* to continue to vary across northern, southern, and eastern parts of the region (Reimann et al. 2018a, 2021, 2023a). Additionally, coastal urban settings are more *likely* to be protected from the impacts of sea level rise due to the cost-effectiveness of protection measures in these locations (Lincke and Hinkel 2018). Coastal residents perceive beaches as a public common good but show an unwillingness to pay for coastal zone restoration and protection (Tourlioti et al. 2021). These examples of potential feedback between climate change and socio-economic development in coastal locations present a high potential for conflict and migration in the region.

52 https://www.unep.org/unepmap/who-we-are/contracting-parties/iczm-protocol

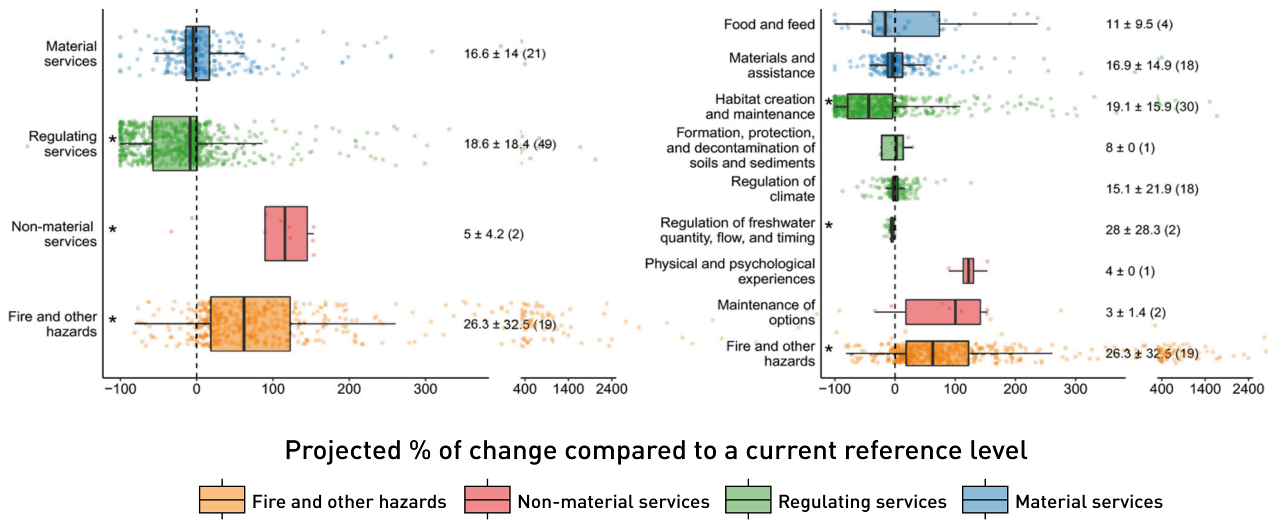


Figure 3.9 | Meta-analyses of projected percentage changes in ecosystem service groups and categories provided by Mediterranean forest ecosystems under 21st-century climate change. Numbers at the end of each box indicate the mean observations per study, standard deviation, and number of studies in the respective ecosystem service group (left) or category (right). Asterisks indicate that the median projected trend differs significantly from zero following the Wilcoxon signed-rank test. Figure adapted from Morán–Ordóñez et al. (2021).

3.5 Ecosystems

3.5.1 Historical and projected climate trends and their impacts on Mediterranean ecosystems

Mediterranean ecosystems (forest, freshwater, coastal, and marine) are vulnerable to environmental change. Within forest ecosystems, increased drought and heat stress arising from climate change are expected to particularly affect broadleaf and drought-sensitive tree species (e.g. *Fagus sylvatica, Castanea sativa,* and *Pinus nigra*) (Ochoa-Hueso et al. 2017; Morán–Ordóñez et al. 2021). In combination with a number of other direct or indirect climate change impacts, especially increases in the occurrence and intensity of wildfires (see also *Sections 1.1.2, 3.2.1, 3.3.1, 3.3.2*) and vulnerability to pests, such changes are therefore expected to hinder the delivery of a number of ecosystem services from forest ecosystems throughout the Mediterranean, especially regulating ecosystem services *(Figure 3.9)* (Morán–Ordóñez et al. 2021).

For freshwater ecosystems, climatic changes are predicted to impact water quantity in the Mediterranean region through significant declines in precipitation and runoff, low flows, and enhanced evaporation rates (Molina-Navarro et al. 2014; Bucak et al. 2017; Green et al. 2017; Coppens et al. 2020). Many freshwater ecosystems are *likely* to face temporary or permanent dry-out risks (e.g. within intermittent-flow rivers and ephemeral streams) (Nabih et al. 2021). In Greece, these changes will result in declining riverine flora and fauna due to reduced freshwater and sediment flows (López-Ballesteros et al. 2020). For wetlands, high-end climate change projections indicate a sharp decline in ecological status due to the impacts of drought, with only 26% of Mediterranean wetlands expected to remain in good ecological status by 2100 (Lefebvre et al. 2019). A decreased hydraulic load can lead to a reduction in nutrient loads and an increase in salinisation (Jeppesen et al. 2015; Yılmaz et al. 2021). In other locations, increased temperature and internal nutrients are likely to cause eutrophication and deteriorating water quality. Increased temperatures can furthermore enhance the ability of invasive species to colonise and outcompete native species and disrupt ecosystem functioning and integrity (Green et al. 2017; Carosi et al. 2021). An increased frequency of other extreme events (floods and heat waves) is also *likely* to affect fish fauna (Santiago et al. 2016; Jarić et al. 2019) and aquatic insects (Conti

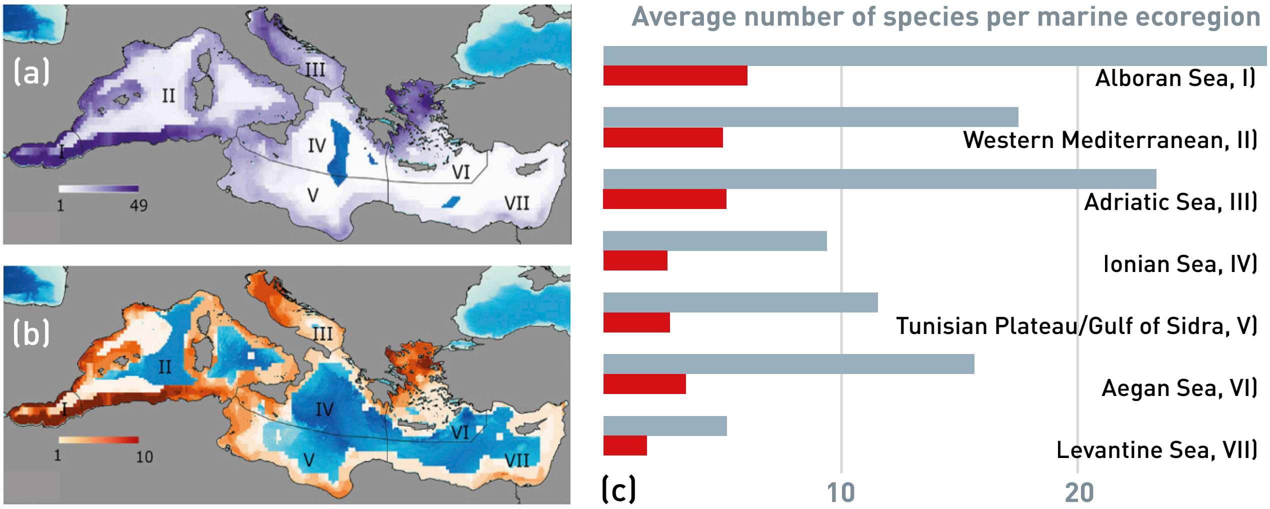


Figure 3.10 | Distribution of threatened marine species vulnerable to climate change throughout the Mediterranean Sea. Panel (a) highlights species with high climatic vulnerability, while panel (b) shows species that are highly exposed to ocean warming. The bar chart indicates the average number of species per region with high vulnerability (grey) and high exposure (red). Source: Chatzimentor et al. (2022).

et al. 2014). Furthermore, declines in the richness of African-Eurasian migratory and breeding waterbird species are forecast throughout the Mediterranean (Nagy et al. 2022). Overall, there is evidence of changing freshwater species ranges under climate change, and future projections foresee a shrinking of freshwater habitats (Pörtner et al. 2022).

Coastal ecosystems are vulnerable to a number of climate change stressors including increased heat stress, sea level rise, and salinisation *(Section 3.4)* (Santos et al. 2014; Erostate et al. 2020). Projections expect 60% of Mediterranean coastal areas to lose fish species by 2040, especially within the western Mediterranean, following increased sea surface temperatures (Clark et al. 2020). Substantial impacts are being additionally projected for subtidal seagrasses (and especially *Posidonia oceanica*). By 2100, seagrasses in the Mediterranean are at risk of functional extinction, with important repercussions for ecosystem services including carbon storage, habitat provisioning, and coastal protection (Chefaoui et al. 2018). Acidification of seawater due to anthropogenic climate change is further expected to contribute to coral bleaching and mortality (Santos et al. 2014).

The Mediterranean Sea has been identified as having one of the fastest changing sea surface temperatures globally, having already increased by 1.48°C over the 1982–2018 period (Azzurro et al. 2019). Beyond increasing average sea surface temperatures, climate change is also resulting in increases in the magnitude and frequency of marine heat waves, thereby disrupting the marine food chain (Moraitis et al. 2019) *(Section 3.2.1)*. Risks of extinction and shifting species distributions are both projected for the region (Garrabou et al. 2021). This is due to increased temperatures affecting species growth, survival, and reproduction, and pushing some species to migrate both into and away from the Mediterranean Sea (Azzurro et al. 2019).

Species declines are being reported throughout the region with respect to the 1980s/1990s period (e.g. in coralligenous assemblages, cold-water species, and zooplankton) and have further been confirmed by declining fisheries landings (Kim et al. 2019; Garrabou et al. 2021; Chatzimentor et al. 2022). Importantly, 93 of 104 threatened species in the Mediterranean are experiencing species decline, largely occurring within the Alboran Sea, Adriatic Sea, and Western Mediterranean *(Figure 3.10)* (Chatzimentor et al. 2022). This is of particular significance given the high proportion of species endemism in the Mediterranean region (25–30%) (Garrabou et al. 2021), and the dependence of marine species on the survival of endemic reefs (Gómez–

Gras et al. 2021). More sessile species are expected to adapt and migrate as a consequence of climate change (Azzurro et al. 2019). The occurrence of new (tropical) species is predicted to increase in the region as a result of increased warming (Benedetti et al. 2019).

3.5.2 Beyond direct climate change impacts: indirect climatic effects and consequences of non-climatic environmental change

Terrestrial ecosystems across the Mediterranean have a long history of human alteration, which has more recently combined with and exacerbated climate change impacts. This is the case for air pollution and land degradation from nitrogen deposition and tropospheric ozone arising from activities associated with industry, agriculture, and transport (Ochoa-Hueso et al. 2017). Beyond pollution, changing land use and management in Mediterranean agroecosystems, and particularly agricultural abandonment resulting in shrub encroachment, also represent an important driver of increased fire risk in the region, and have been found to further amplify the effects of drought (Rolo and Moreno 2019; Elsen et al. 2022). Additionally, policy targets are altering forest management to ensure the delivery of services including carbon sequestration, bioenergy production, habitat provisioning, climate adaptation, and erosion regulation. The achievement of some or all of these targets is *likely* to induce more profound changes in Mediterranean forests than those ensuing from the impacts of environmental changes (Morán-Ordóñez et al. 2020).

Freshwater ecosystems have been, and are *likely* to be, adversely affected by anthropogenic drivers of environmental change beyond climate change, including water abstraction for irrigation and subsequent increases in salinisation. This may result in temporary or permanent habitat loss for freshwater species (Green et al. 2017), yet in some regions there is evidence that climate change has a greater effect on freshwater ecosystems than land use change dynamics (Bucak et al. 2017). Increased construction of dams and reservoirs has similar adverse implications for freshwater ecosystems as a result of reduced water quantity, sediment accumulation, and increased salinity downstream (Taylor et al. 2021). Pollution has an additional negative impact, including from nutrient enrichment associated with agriculture and urban pollution from suboptimal sewage treatment (Paredes et al. 2021; Pereda et al. 2021). These impacts all pose a threat to freshwater biodiversity in the Mediterranean and its endemic fish species, which are reported to have undergone declines in the past few decades (Meke et al. 2012; Yeğen et al. 2015; Küçük et al. 2016; MWO 2018).

Mediterranean coastal ecosystems are impacted by a range of non-climatic drivers of environmental change due to the high population density and anthropogenic activity within coastal regions, and climate change is therefore largely exacerbating pre-existing pressures and risks (*Section 3.4*; Santos et al. 2014). Over-development of coastal Mediterranean regions is placing pressure on coastal lagoons and aquifers both via reduced water availability and through increased pollution, each stemming from often unregulated residential, industrial, and agricultural withdrawals and emissions (Drius et al. 2019; Erostate et al. 2020; Llorca et al. 2020). River discharge is also an increasing source of pollution, and the primary cause of eutrophication in coastal waters, resulting in algal blooms and hypoxia, especially within the Adriatic and Aegean seas, with adverse impacts on endemic species (Macias et al. 2018; Ontoria et al. 2019). Two additional important pressures on coastal ecosystems are the increased presence of invasive species, in particular from the Red Sea (Zamir et al. 2018), and overfishing (Albouy et al. 2013). Drivers of change are also situated upstream of coastal areas, where dams for irrigation or hydropower generation are reducing sediment flow to the coastline with implications for deltas and coastal zones.

Increases in the number of non-indigenous species in the Mediterranean are also the result of marine traffic (primarily through the Suez Canal), aquaculture, and the aquarium trade (Azzurro et al. 2019). Further drivers of marine ecosystem change in the region are overfishing, eutrophication, and ship collisions (Garrabou et al. 2021; Chatzimentor et al. 2022). While Marine Protected Areas (MPA) across the Mediterranean have been found to be effective in safeguarding marine ecosystems, concerns have been raised over a lack of monitoring, and more rigorous consideration of the impacts of environmental change. This should be taken into consideration in addition to expanding the MPA network beyond the north-western Mediterranean (Benedetti et al. 2019;

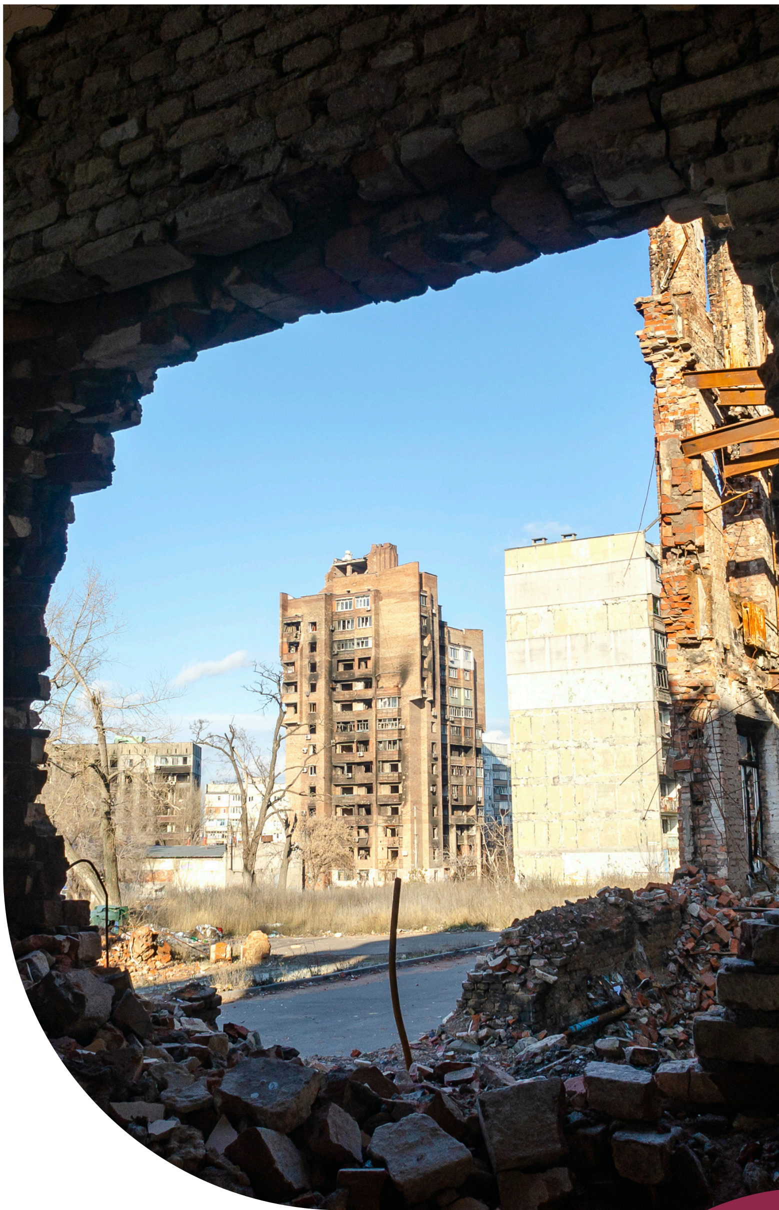
Garrabou et al. 2021). Climatic and non-climatic impacts on Mediterranean marine ecosystems are likely to affect regional livelihoods, not only through maintaining food provisioning, but also through impacts on tourism and coastal protection (Garrabou et al. 2021).

3.5.3 Summary: implications for livelihoods, migration, and conflict

A deterioration in the state of freshwater, coastal, marine, and terrestrial ecosystems of the Mediterranean will result in a reduced supply of ecosystem services, and therefore lead to adverse impacts on human well-being. Some of these impacts will lead to lost incomes and livelihoods, primarily as a result of declining agricultural yields (including from increased coastal salinisation and declining irrigation capabilities), reduced forest productivity due to the deteriorating health and growth rate of trees, declining fish stocks, disrupted port operations, and reduced tourism opportunities across all ecosystems, and in coastal areas in particular (Ali et al. 2022). Depending on the severity of the impact, existing options for ecosystem resilience through adaptation, and opportunities for livelihood diversification, these trends have the potential to result in permanent forms of displacement as people are forced to seek alternative livelihood opportunities.

Because of this variation in adaptation capacities and vulnerabilities (in addition to the scale of environmental pressures), implications for livelihoods are not uniform throughout the Mediterranean region. A key area of concern is the Nile Delta in Egypt, where sea level rise and increased desertification are gradually eroding some of the region's most productive ecosystems (Warner et al. 2010). In some cases, regions facing this kind of gradually progressing ecosystem deterioration have started exploring possibilities for relocation (e.g. to upland metropolitan areas, as discussed for coastal regions in Spain in Fatorić et al. (2017)). This is usually perceived as a last-resort option by vulnerable populations, including those at greatest risk of livelihood loss, residential damage, and health effects (Fatorić et al. 2017). Displacement and migration are also likely to occur in regions at high risk of ecosystem disruption from destructive hazards, including flooding and wildfire.

Assessing the impacts of climate and environmental change through an ecosystem services lens makes it possible to identify dependencies of multiple functions and (economic) sectors on key ecosystem properties, and therefore reveals areas of potential competition and conflict. Competing claims on Mediterranean wetlands have, for example, been identified in terms of biodiversity conservation, flood protection, hydropower generation, and irrigated agriculture (Pulido-Velazquez et al. 2023). When situated across transboundary areas, these claims can furthermore become a cause of international tension (Taylor et al. 2021). Coastal areas are similarly under pressure to deliver multiple ecosystem services as a result of a high concentration of people and economic activity, and may therefore also see increased competition and conflict following a deterioration in their ecological state (Fatorić et al. 2017).



3.6 Energy

3.6.1 Environmental change impacts on the energy sector

Environmental changes are expected to impact the energy sector, including production, transportation, distribution, and final end use *(Table 3.2).* Furthermore, increasing temperatures and extreme weather conditions will increase the dependency on ever increasing energy consumption to improve indoor environmental conditions.

The use of energy represents by far the largest source of greenhouse gas emissions from human activities, as three-quarters of global greenhouse gas emissions are linked to burning fossil fuels for energy used for various purposes. Climate change puts energy security at risk, as it affects many facets of the energy cycle including production. This is particularly relevant with regard to the energy demand for space cooling in buildings and industry to maintain acceptable indoor conditions. In addition, the entire infrastructure of the energy industry — power plants, grids, transport facilities, etc. — is put under stress due to increasing temperatures and extreme weather conditions. Finally, climate change can alter energy generation potential, because, for example, changes in the water cycle affect the ability to generate hydropower, and the effective cooling of nuclear power plants.

Thermoelectric plants burn hydrocarbons (coal, oil, natural gas) or utilise nuclear fuels to operate the thermodynamic cycle of power production. These plants require large amounts of water for electricity generation, mainly for cooling purposes, making their performance and cooling capacity strongly dependent on and highly sensitive to reduction in water availability as a result of environmental change (Förster and Lilliestam 2010; Attia 2015; Lee et al. 2018; Petrakopoulou et al. 2020). Renewable energy sources (RES) (solar, wind, geothermal, biomass, and hydro) are also significantly affected by climate change. Not only do long-term variations in solar and wind energy availability need to be reassessed under changing climate conditions, but the actual operation of solar photovoltaics, wind turbines, and other RES plants is also affected (Yang et al. 2022).

While the efficiency of solar panels decreases with increasing ambient temperature, hampering their energy output, increasing solar irradiance is expected to partly compensate for this effect (Dubey et al. 2013; Panagea et al. 2014; Jerez et al. 2015).

Wind turbines may experience unforeseen pressures from climate change-induced extreme wind situations and consequently suffer from a loss of structural stability and resilience. Atmospheric conditions enter into the design and operation of wind turbines and wind farms, and, for example, a small variation in wind speed usually has a sizeable impact on energy output (Pryor and Barthelmie 2010).

Geothermal energy is practically independent of climate factors. Simulation results however indicate that about 10% of operating hours may require additional technical measures, like peak source support, smart management, and buffers to limit pumping ramp rate (Ciapała et al. 2021). Management of geothermal energy production can therefore utilise modern techniques to smooth production in accordance with demand fluctuations.

Bioenergy has been promoted as a renewable energy policy component offering an alternative to fossil fuels, with climate change mitigation benefits. However, these benefits have come under scrutiny, and research has focused on the long payback times for forest-based bioenergy, and indirect effects on land use and food production, biodiversity loss, and land degradation (Koponen et al. 2018). Various attempts to quantify the environmental-change effects of bioenergy systems have been made, and results vary due to the different treatment of biogenic carbon fluxes and other considerations (Brandão et al. 2019). Increases in ambient temperatures may increase biomass forest production, especially in northern latitudes. However, for the Mediterranean Basin, the expected decrease in precipitation will reduce, if not reverse, any positive effects (Poudel et al. 2011; Peñuelas et al. 2017).

Hydropower is a renewable, low-emission source of electricity, and it contributes significantly to the reduction of GHG emissions and energy supply security. However, as it relies on sufficient and predictable surface water flows, environmental changes are likely to alter river discharges, impacting water availability and ultimately hydropower generation (Berga 2016) . The impacts of climate change on hydropower development are complex, and their effects depend on factors such as local hydrological conditions and geographic features (Shu et al. 2018; Wasti et al. 2022). Extended droughts in an area like the Mediterranean Basin (Ozkaya and Zerberg 2019; Altın et al. 2020) are likely to lead to decreasing hydropower generation and a complete collapse, if reservoir levels fall below intake structures.

Battery storage systems are needed, because renewable energy, especially solar and wind, are not always available, and demand can outpace supply. A power grid (which is an extensive system), and the need for efficient storage of vast amounts of electrical energy entails significant investments in electricity storage, that is in battery units (Jones et al. 2020).

Examples of sector-specific impacts

Coal mining. Climate hazards such as heavy precipitation, drought, and heat induced by climate change will become more frequent and intense, increasing the physical challenges to mining operations, altering the water supply to mining sites, and disrupting operations. Mining regions not accustomed to water stress are projected to become increasingly vulnerable. Flooding from extreme rains can also cause operational disruptions, including mine closure, washed-out roads, and unsafe water in tailing dams. Extreme weather combined with sea level rise can damage processing or transportation infrastructure located near coastlines. Widespread decarbonisation efforts across industries could create major shifts in commodity demand for the mining industry (Rüttinger and Sharma 2016).

Petroleum operations. Oil and gas infrastructure, especially near coasts and offshore, face increasing challenges and impacts from environmental change and extreme weather conditions, which also increases the risk of associated oil spills. The key climate change drivers in coastal and offshore regions can be characterised as air and water temperature, precipitation, sea level rise, and extreme storm events (Dong et al. 2022).

Grid infrastructure. Changing environmental operating conditions impact infrastructure utilisation and performance *(Table 3.3).* Climate trends will transform the performance and risk exposure of grid assets. Building a system that could operate reliably in any possible climate future may imply prohibitive costs and prove unnecessary. Certain risks should therefore be accepted (Sathaye et al. 2013; Panteli and Mancarella 2015; Brockway and Dunn 2020).

Energy demand. Electricity is set to become the main energy carrier, accounting for over 50% of total final energy consumption by 2050 in the 1.5°C scenario. Renewable energy deployment, improvements in energy efficiency, and the electrification of end-use sectors are expected to contribute to this shift. In addition, modern biomass and hydrogen are both likely to play more significant roles, providing 16% and 14% of total final energy consumption by 2050, respectively (IRENA 2023). The energy consumption of buildings accounts for over 40% of energy demand in the EU, and climate change impacts pose a number of challenges for the building sector. It is primarily the increase in ambient temperature, and the subsequent need for increased air-conditioning usage, that is considered the main challenge and impact on demand for electricity (Angeles et al. 2018; Bazazzadeh et al. 2021; Colelli et al. 2022).

3.6.2 Implications for livelihoods, migration, and conflict

The pursuit of improved living conditions leads to increasing energy consumption, with an ever-increasing demand for wet appliances (washing machines, dishwashers, etc.), cold appliances (fridges, freezers, air conditioners, etc.), consumer electronics, lighting, and cooking. Climate change, with its soaring temperatures and frequent extreme weather conditions, is going to have an even greater impact on energy needs, especially in areas of the southern Mediterranean Sea, which already face strong migration pressures. These pressures are expected to increase. While the generation of sufficient electricity has to be seen in the context of the energy-water nexus, the stable provision of energy to the consumers will depend on a functional energy infrastructure. Consequently, these objectives may be associated with potential conflict among populations striving to obtain energy and water resources (Lucca et al. 2023)

The IEA World Energy Outlook 2023 shows an ever-present risk of disruption in energy supply, due to the unsettled global economy. Russia's invasion of Ukraine and conflicts in the Middle East make for a world energy situation that runs counter to a smooth energy transition process, while geopolitics focuses on the energy markets, especially for oil and natural gas. This is counterbalanced to some extent by the lowering of photovoltaic prices, the green hydrogen economy, and the efforts of many countries to implement a strategy to break away from fossil fuel subsidies. A new, clean energy economy seems to be emerging, with solar PV, electric vehicles, and subsequent investment in clean energy technologies on the rise. In addition, green hydrogen has the potential to act as a catalyst for sustainable development in developing countries (UNIDO et al. 2024).

Table 3.2 | **The energy cycle schematic, and the main areas of climate change impact on its operation.**

THE ENERGY CYCLE			
SUPPLY SIDE	**PRODUCTION**	**TRANSPORT**	**DEMAND SIDE**
Coal, Oil, Natural gas, Nuclear Solar energy, Wind energy, Geothermal, Biomass, Hydraulic	Power stations, PV parks, Wind parks	Electricity grid, Oil tankers, Pipelines	Buildings, Transport, Industry
CLIMATE CHANGE AREAS OF IMPACT			
Construction, Mining, Drilling, Fuel transport	Power operation, Land use, Water use, Maintenance	Grid operation, Shipping, Maintenance	Operation, Maintenance, Replacing

Table 3.3 | **Examples of climate change effects on the electricity.**

GENERATION	TRANSMISSION	DISTRIBUTION
Decreasing availability of water may affect the generation of hydroelectricity, the efficiency of PV farms, and the operation of thermal power stations	Warmer temperatures and heat waves can reduce the transmission capacity of lines and put pressure on substations	Heat waves and more frequent and intense wildfires can damage distribution lines, transformers, and substations

3.7 Interactions between sectors

There are strong linkages between migration, water availability, food production, coastal ecosystems and development, public health, the energy sector, and environmental change. Climate change affects water availability, food security, and therefore human health through the increased occurrence of climate hazards such as drought, floods, and heat waves *(Figure 3.11)*. The effects of such processes are more apparent in the Mediterranean's southern and eastern regions, where lower precipitation and less advanced irrigation technologies make it difficult to meet agricultural needs and rising demands for food and water. Population is projected to increase in these regions up to 2100 under all socio-economic scenarios (SSPs) compared to 2010. The coastal Mediterranean region's high level of urbanisation will worsen conditions in cities because of the 'urban heat island effect'. This will result in increased demand for water to maintain green spaces in cities. In addition, more energy will be needed for space cooling in order to maintain acceptable indoor living conditions, particularly for the most vulnerable populations — the elderly, the sick, pregnant women, and children. Marine heat waves, which persist longer and become hotter, are predicted to put the fishing industry at medium to high risk, since they reduce productivity and revenue.

Over-development of coastal Mediterranean regions is placing pressure on coastal lagoons and aquifers both via reduced water availability, and through increased pollution, each stemming from often unregulated residential, industrial, and agricultural withdrawals and emissions. Land losses in coastal deltas are projected to be intensified by mean sea level rise. Increases in the number of invasive species in the Mediterranean are only partly the result of climate change disruptions to sea temperatures, and are more significantly linked to marine traffic.

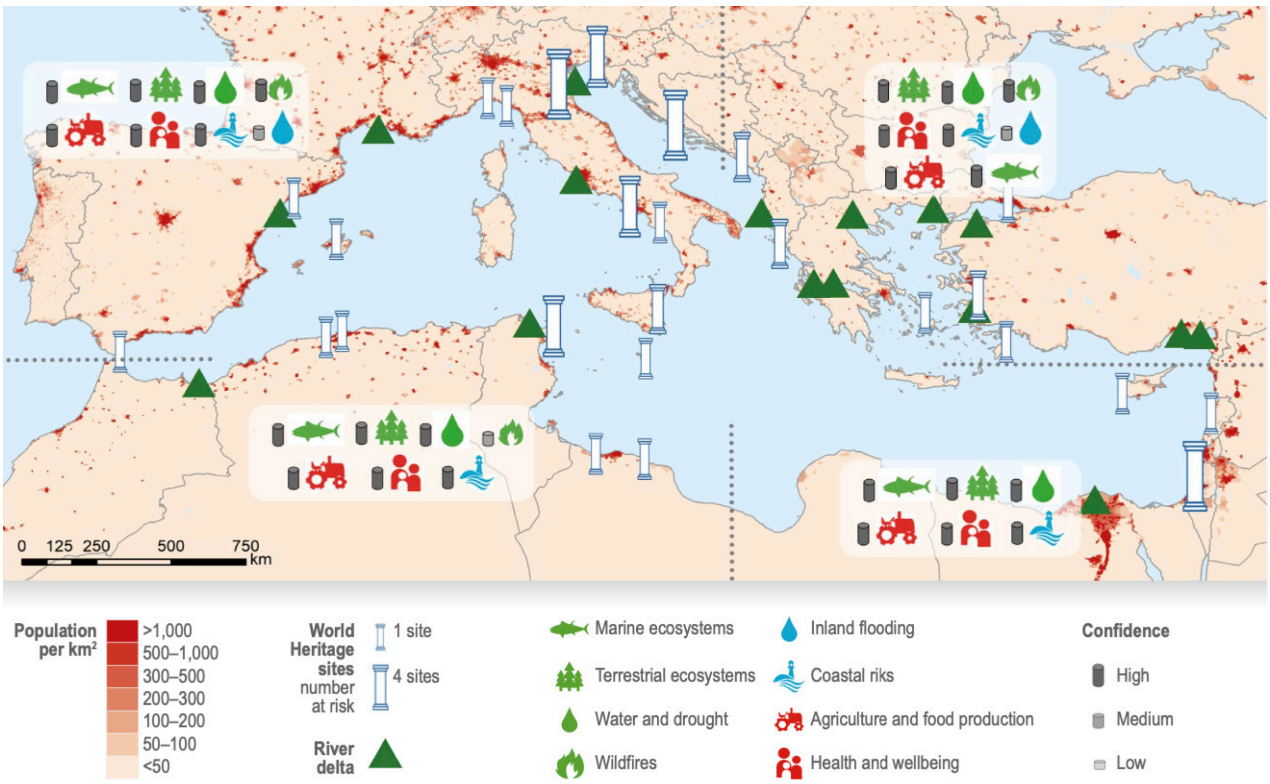


Figure 3.11 | Key risks in the Mediterranean and their location across the Mediterranean region for SSP5-RCP8.5 by 2100. Source: Figure CCP4.7 from Ali et al. (2022), based on: Reimann, Merkens, et al. 2018; Reimann, Vafeidis, et al. 2018; Wolff et al. 2018 (see Sections CCP4.3.2–6 and Tables SMCCP4.2a and b in Ali et al. 2022 for details). Risks to World Cultural Heritage sites from flooding or erosion due to sea level rise in multiple locations (Section CCP4.3.5 in Ali et al. 2022), and Mediterranean river deltas are hotspots of vulnerability to climate change (Section CCP4.3.2 in Ali et al. 2022). The population exposed to risks is mapped for an SSP5-RCP8.5 pathway. Adaptation can reduce these risks (Section CCP4.4 in Ali et al. 2022).

Relative sea level rise will not only affect coastal populations and ecosystems due to the gradual submergence of low-lying land but will also result in more frequent and intense coastal flooding and erosion due to extreme sea levels (Burak et al. 2024). Habitability is predicted to decline, particularly in the dry southern Mediterranean region. This will put pressure on people and settlements from both the coast (because of sea level rise) and inland areas (due to desertification). Furthermore, as coastal flooding increases in frequency and intensity due to extreme sea levels, it may lead to human deaths, temporary displacement, and permanent population movement away from the coast. Seawater intrusion into coastal aquifers and soils associated with sea level rise may affect around 30% of irrigated farmlands. Several delta areas are already considered to have salt-affected soils, and coastal aquifers may be salinised, which could endanger people's livelihoods by lowering agricultural yields, restricting access to safe drinking water, and decreasing profits from the tourism industry.

Extreme weather conditions affect conventional energy production operations such as coal mining and oil and natural gas drilling. Power plants, which depend on substantial amounts of cooling water, are *likely* to have to be adjusted to operate at different temperature levels with reduced efficiency. Also, extreme weather conditions alter and affect the renewable energy production of solar photovoltaics, wind turbines, hydroelectricity plants (rivers, lakes, dams), and biomass production. Environmental changes are expected to impact transport networks, including electricity networks, and also the transport of conventional fuels. Overhead cables and pylons for electricity transmission are particularly vulnerable to increasing temperatures and erratic wind conditions. At the user end, climate change will, among other things, alter weather conditions in many areas around the planet, increasing temperatures and changing wind conditions and precipitation patterns. This will affect living conditions and therefore energy dependence for the vast majority of the population.

Conflicts and human migration, driven by a combination of climate-related and non-climate related factors, have significant implications for public health in the Mediterranean Basin. Conflicts

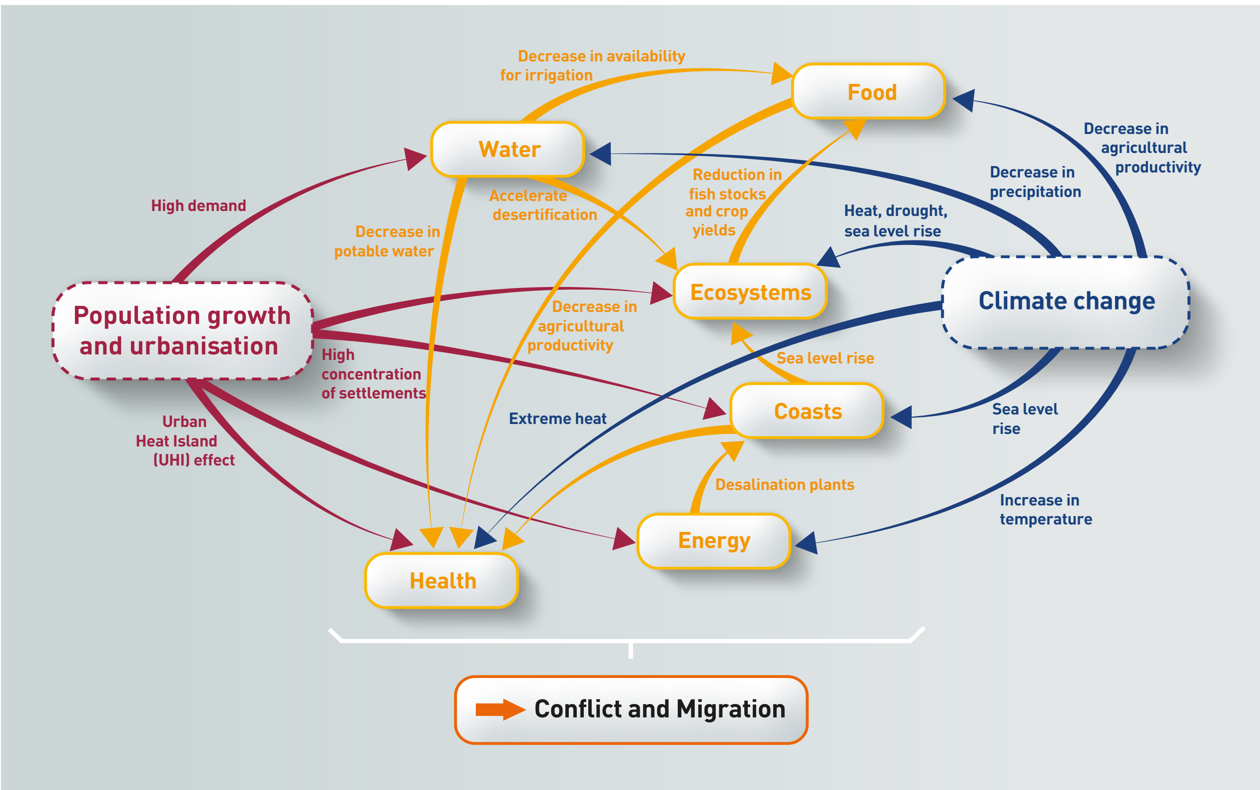


Figure 3.12 | Links between climate change and socio-economic changes and their consequences for the individual sectors.

beyond the Mediterranean region (for example the Ukraine war) can have indirect consequences for the health of Mediterranean populations. Immigrants and refugees face disproportionately high rates of poverty and inadequate living conditions in their destination countries. The elderly, the chronically ill, people who work outdoors, and those from low-income backgrounds are particularly susceptible.

In summary, the different sectors discussed in this chapter are affected by both environmental changes and socio-economic changes across the Mediterranean region. The impacts on these sectors are highly interconnected *(Figure 3.12)*, therefore resulting in compounding stresses on human livelihoods. The interaction of impacts across sectors, and their compounding effects, have the potential to become triggers for conflict and migration across the region.

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