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MANAGING FUTURE RISKS AND BUILDING SOCIO-ECOLOGICAL RESILIENCE

Coordinating Lead Authors:
Athanasios T. Vafeidis *(Germany/Greece)*

Lead Authors:
Ameer A. Abdulla *(Spain/Egypt)*, Alberte Bondeau *(France)*, Lluis Brotons *(Spain)*, Ralf Ludwig *(Germany)*, Michelle Portman *(Israel)*, Lena Reimann *(Germany)*, Michalis Vousdoukas *(Italy/Greece)*, Elena Xoplaki *(Germany/Greece)*

Contributing Authors:
Najet Aroua *(Algeria)*, Lorine Behr *(Germany)*, Francesco Dottori *(Italy)*, Joaquim Garrabou *(Spain)*, Christos Giannakopoulos *(Greece)*, Guillaume Rohat *(Switzerland/France)*, Elias Symeonakis *(UK/Greece)*

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Executive summary

The Mediterranean Basin is experiencing major changes in environmental conditions, which can introduce new challenges to the resilience of its natural and human systems. This situation is combined with rapid and spatially diverse socio-economic development in the region, mainly in terms of demographic trends and settlement patterns, thus leading to higher exposure to environmental hazards. Furthermore, new risks are expected to emerge from interactions between drivers and impacts across sectors, thus increasing the vulnerability of natural systems and human populations.

Future risks in the Mediterranean region will be determined by hazard characteristics (intensity and frequency) and by developments in socio-economic conditions that determine a society's adaptive capacity to cope with these hazards. Current risks to human population, economies and ecosystems will increase as a result of changes in the patterns of droughts, wildfires, soil degradation, desertification, sea level rise, heat waves and river flooding, and other pressures, potentially leading to greater impacts. These impacts can be further exacerbated by the occurrence of compound and cumulative events, which can seriously challenge the adaptive capacity and resilience of biophysical and human subsystems. Coping with these risks, adapting to change and increasing the resilience of Mediterranean systems will be essential for ensuring sustainable development in the region.

Successful practices and initiatives for risk reduction and management, such as water-sensitive urban design, implementation of nature-based solutions, operational flood forecasting systems, or collaborations within cities' networks, are already being implemented across the region. However, these efforts are often slow in catching on or fail to consider the rising pressures in the light of changing environmental conditions and developmental demands. Understanding these changes and demands is essential for managing future risks. In this context, Mediterranean-wide initiatives such as establishing long-term monitoring schemes to obtain data missing in many parts of the basin; accounting for differences in monitoring and reporting between northern (EU), eastern, and southern countries of the region; advancing (climate) modeling techniques for the short-term prediction of extreme events (e.g., heat, flooding), and improvements in seasonal forecasts are essential for supporting future management and adaptation strategies and for enhancing resilience. Furthermore, public participation in the development and implementation of these strategies is necessary in order to increase local relevance and acceptance of proposed strategies, and is particularly important for building a resilient society.

The level of future risk in the Mediterranean Basin will largely depend on the timing of adaptation and on how soon and how effectively sustainable development is pursued. In particular, addressing more pressing natural and socio-economic challenges in several countries in the Middle East and North Africa is essential for avoiding the widening of the development gap between northern, southern, and eastern countries of the region. Therefore, developing joint, region-wide, and integrated management and adaptation approaches that treat multiple hazards in a holistic manner is of utmost importance for sustainable development in the entire region. Nonetheless, no one-size-fits-all strategy exists, but each measure needs to be tailored to the respective local conditions. Regional co-operations, e.g. in the form of active participation in regional-to-global initiatives and networks concerned with building socio-ecological resilience, will be an important step forward in transferring knowledge on successful practices and innovation across the Mediterranean nations.

6.1 Introduction

Scenarios of environmental and socio-economic change for this century suggest severe challenges to the resilience of natural and human systems worldwide. For climate, such challenges will be particularly posed by extreme events, such as increased temperature anomalies *(Section 2.2.4)* and potential changes in storm intensity *(Section 2.2.2.3)*, as well as by slow onset events such as sea level rise *(Section 2.2.8)*. From a management and policy perspective, this means that these changes increase the vulnerability of certain groups that are natural resource-dependent and increase the need to enhance the resilience of ecosystems and human systems. Finally, they will also increase the need for efforts to reduce local stressors and identify adaptation options.

The Mediterranean Basin is experiencing major changes in environmental conditions, combined with rapid and spatially diverse socio-economic development. These factors combined are exerting increased pressure on natural systems and human societies in the region. At the same time, new risks may emerge from interactions between drivers *(Section 2.6)* and from the interactions of impacts across sectors (Cramer et al. 2018), which may result in greater impacts, while increasing the vulnerability of less resilient natural systems and populations. These risks can affect the provision of services from natural systems and lead to severe disruptions in social systems.

Chapter 6 deals with managing future risks, identifying adaptation options and building capacity for resilience to climate and environmental changes. Addressing this aim, the chapter discusses three key components of emerging policy needs in the basin. The first component is the current understanding on the trajectory, intensity and spatial extent of future risk for the principal hazards, and associated policy considerations of the region. Secondly, the chapter outlines the current management and adaptation approaches and prevalent governance frameworks for coping with these risks. The third component critically reviews a range of examples of adaptation and mitigation for sectoral approaches, while considering case studies from Mediterranean-type environments.

Chapter 6 identifies a number of innovative and successful practices for achieving sound and sustainable development in countries of the Mediterranean Basin. Successful adaptation case studies involve stakeholder participation, structural political and economic change, gender considerations and weather-indexed insurance schemes. Successful mitigation involves options with clear societal benefits, such as energy cooperatives, energy efficiency, or regional cooperation. The final part of this section discusses potential interactions between hazards and sectors, which may lead to increased impacts. It further includes proposals to improve synergies between adaptation and mitigation practices and suggestions to promote Mediterranean cooperation and networking for building resilience, while also focusing on education and capacity-building.

6.2 Human health impacts

6.2.1 Future health risks

Environmental change can lead to a wide range of impacts on human health in Mediterranean countries (*Sections 5.2.3* and *5.2.4*). The most well-known impacts are direct impacts, e.g., extreme temperatures, cold and heat waves leading to cardiovascular and respiratory diseases and death (Gasparrini et al. 2017), wildfires leading to lethal injuries and respiratory diseases (Reid et al. 2016), and direct physical injuries and deaths resulting from extreme weather events, such as intense rainfall, river flooding, and storms (Forzieri et al. 2017). Impacts on human health can also be indirect, e.g., climate-related changes in food availability and quality that threaten food security (Deryng et al. 2016), increased variability of rainfall patterns that jeopardizes the availability and quality of freshwater (Koutroulis et al. 2016; Flörke et al. 2018), worsened air quality causing respiratory illnesses (de Sario et al. 2013; Doherty et al. 2017), and climate-driven increase in vector-borne diseases (Negev et al. 2015). The extent to which environmental change affects human health largely depends on the vulnerability of the exposed populations, that is, their ability to face and cope with climate-related hazards (IPCC 2012). Just as, for example, climate change is altering the climate system, socio-economic development and demographic growth are shaping the future vulnerability of populations in the Mediterranean Basin, with contrasting trends depending on the type of socio-economic trajectory (O'Neill et al. 2017; Reimann et al. 2018a; Kok et al. 2019). Urban areas along the Mediterranean coast are especially affected by climate change impacts on health because these areas concentrate people and assets (Watts et al. 2015). Urban areas often intensify climate-related hazards, e.g., hotter temperatures during heat waves due to the urban heat island effect (Papalexiou et al. 2018) and increase in run-off and flooding during extreme precipitation events due to soil sealing (Romero Diaz et al. 2017).

Heat-related morbidity and mortality are projected to increase substantially throughout the Mediterranean countries, under all climate scenarios *(Sec-*

tion 5.2.5.2). Impacts are expected to be the greatest in urban areas where people are concentrated and where the urban heat islands lead to higher inner-city temperatures (Yang et al. 2016). Future heat-related health risks are well-documented, with a large number of case studies spread across the Mediterranean Basin. Examples include (but are not limited to) a ~3- to 9-fold increase in the heat-related mortality rate in Cyprus (Heaviside et al. 2016); a 50-fold increase in mortality (compared to the current situation) on average across southern Europe by the end of the century (Forzieri et al. 2017) and a substantial difference in the increase of mortality between RCP2.6/RCP4.5 and RCP8.5 scenarios (Gasparrini et al. 2017; Kendrovski et al. 2017) *(Section 5.2.5.2).* In contrast, cold-related mortality is projected to decrease under all scenarios (Forzieri et al. 2017) *(Section 5.2.5.3).* It is also worth noting that changes in socio-economic and demographic conditions such as urbanization, demographic growth, and aging are also expected to further increase the burden of heat-related morbidity and mortality in Mediterranean countries (Rohat et al. 2019b, 2019a).

In contrast to other parts of the world, climate change is expected to lead to an overall increase in ground-level ozone- and fine particulate matter-related mortality in Mediterranean countries (Silva et al. 2016), with the exception of high-end climate change scenario RCP8.5, which leads to an increase in the health burden of air pollution in most Mediterranean countries (Silva et al. 2017). However, the significant uncertainties that exist in the trend directions and in risk estimates, that are primarily linked to the uncertainty in future types of emissions must be noted (Doherty et al. 2017).

Temperature rise will expand the habitat suitability for vectors, such as mosquitoes and sandflies (Negev et al. 2015; Semenza and Suk 2018; Hertig 2019) to most of the Mediterranean Basin by the end of the century and increase the transmission risk of the diseases they can carry, such as dengue, West Nile Fever and leishmaniasis (Bouzid et al. 2014; Semenza et al. 2016; Liu-Helmersson et al. 2019) *(Section 5.2.5.4)*. One exception is the reduction of habitat suitability for *Aedes albopictus* in the southernmost parts of Europe (Caminade et al. 2012; Proestos et al. 2015), leading to a reduction of climatically suitable areas for the transmission of Chikungunya (Fischer et al. 2013). Changes to the hydrological cycle caused by climate changes are expected to further amplify such health issues and lead to increased fatalities. Erratic precipitation and extreme events and floods could support the flourishing of bacteria, parasites and algal blooms, including the protozoan parasites *Cryptosporidium,* hepatitis A viruses, *Escherichia coli* bacteria, and more than 100 other pathogens. The increase in human mobility also plays a crucial role in spreading vector-borne diseases throughout the Mediterranean Basin in newly suitable habitats (Thomas et al. 2014; Roche et al. 2015; Hertig 2019; Kraemer et al. 2019).

The combination of longer fire seasons and more frequent, large, and severe fires – triggered by increased droughts and land-use change (Turco et al. 2014; Knorr et al. 2016) – is projected to lead to greater fire risk and casualties, particularly in sub-urban areas (Forzieri et al. 2017) *(Section 2.6.3.3).* Similarly, more intense and frequent extreme precipitation events are expected to trigger a strong increase in flash flood-related injuries and mortalities throughout Mediterranean countries (Gaume et al. 2016) *(Section 3.1.4.1).* Floods can further damage water infrastructure, contaminate freshwater supplies, heighten the risk of water-borne diseases, and create breeding grounds for disease-carrying insects, especially threatening those with already limited access to water and sanitation (WHO 2017). The combination of demographic growth and changing diets is expected to lead to higher food demand across the region (Paciello 2015), while changes in extreme events such as droughts, heat waves, and extreme precipitation are projected to decrease crop and livestock yields substantially (Bernués et al. 2011; Deryng et al. 2016) *(Section 3.2.2.1).* This is particularly the case in the southern part of the Mediterranean Basin.

6.2.2 Management approaches, governance, and adaptation for health risks

National adaptation policies have been adopted in a large number of Mediterranean countries, often covering and acting on large-scale health topics such as extreme heat, air pollution, and vector-borne diseases (Negev et al. 2015). Although national governments have an important role to play in reducing the burden of climate change on human health, it is at the local scale that most actions and measures are taken (Paz et al. 2016). In fact, cities and municipalities in the Mediterranean Basin are at the forefront of climate change adaptation, particularly with regard to climate change impacts on human health, and often drive the regional effort to better anticipate and prepare for the adverse effects of climate change on human health and well-being (Reckien et al. 2018).

City-level adaptation is, more often than not, preferred to national-scale adaptation to decrease the vulnerability of the local population. This is accomplished through measures that include (but are not limited to) the improvement of housing and infrastructure, the education and awareness-raising of the most vulnerable communities, the implementation of early warning systems, the strengthening of local emergency and healthcare services, and the general strengthening of the community's and local institutions' adaptive capacity (Larsen 2015; Liotta et al. 2018). City-level adaptation can also directly target the reduction of climate-related hazards, such as building multi-usage buffer zones to reduce flood risk and to decrease the urban heat island (Yang et al. 2016).

Interestingly, management approaches sometimes attempt to develop adaptation measures that also affect climate change mitigation and/or that trigger health benefits, such as using green roofs to retrofit existing buildings (Gagliano et al. 2016) and transforming the transportation systems to mitigate emissions and reduce air pollution (WHO Europe 2017).

6.2.3 Case studies

It is important to note that most adaptation actions are impact-, context- and place-specific and there is no one-size-fits-all adaptation measure to reduce climate impacts on human health. Adaptation measures can take a wide range of forms, be triggered by different events, operate on different spatial and temporal scales, and be associated with different implementation constraints (Fernandez Milan and Creutzig 2015; Holman et al. 2018).

A number of Mediterranean cities have developed adaptation plans that specifically target the reduction of human health impacts. A significant part of the actions depicted in such climate adaptation plans are broad and unspecific (Reckien et al. 2018), which can constitute a bad practice and often do not mention potential negative effects, such as the increase in inner-city temperature and air pollution due to the systematic installation of air conditioning (Salamanca et al. 2014). Certain adaptation plans depict context-specific and quantified actions, such as in the city of Barcelona, which for instance, plans to increase its urban green areas by 1 m² per city resident by 2030 in order to decrease the urban heat island in case of extreme heat and increase water infiltration in the event of flash flooding (Barcelona Sostenible 2015).

For regional climate-related hazards, such as vector-borne diseases, a multi-country and trans-boundary approach to adaptation is crucial (Negev et al. 2015) and has been implemented over the past decades. In its current form, the MediLabSecure project[40] covers all Mediterranean countries and aims at preventing vector-borne diseases in these countries through scientific research and concrete actions.

6.2.4 Innovation

Climate change vulnerability assessments with a strong focus on human health have been undertaken over the past few years for cities without dedicated adaptation plans, including case studies for Cairo (Katzan and Owsianowski 2017), Nicosia (Kaimaki et al. 2014), and Antalya (Antalya Metropolitan Municipality 2018). These studies provide a strong scientific basis for the design of context-specific adaptation plans in the years to come. Collaboration within networks of cities with the goal to act on climate change (including adaptation to human health impacts) is promising in terms of identifying and sharing knowledge on best practices and concrete actions (Román and Midttun 2010; Rosenzweig et al. 2018). For example, cities such as Tel Aviv, Rome, Thessaloniki, Ramallah and Byblos are members of the "100 Resilient Cities"[41] network, Venice is a member of the "C40 Cities"[42] network and its program for connecting delta cities, and numerous cities are members of the Global Covenant of Mayors for Climate and Energy.

The integration of climate adaptation and mitigation plans within a unique climate plan is rarely achieved, but appears to be an efficient way to design measures that benefit both adaptation and mitigation (Reckien et al. 2018). The city of Athens has recently entered the circle of cities to have done so, with results on the reduction of human health impacts expected to come in the next few years (City of Athens 2017).

[40] https://www.medilabsecure.com/home.html

[41] https://www.rockefellerfoundation.org/100-resilient-cities/

[42] https://www.c40.org/

6.3 Water security

The Sustainable Water Partnership (SWP)[43] defines water security as "the adaptive capacity to safeguard the sustainable availability of, access to, and safe use of an adequate, reliable and resilient quantity and quality of water for health, livelihoods, ecosystems and productive economies". This embracing definition reveals the pivotal role water security plays on all levels for reaching the ambitious goals laid out by the UN's Sustainable Development Goals (UN 2015; Bhaduri et al. 2016). Diametric to water security is water scarcity, a state reached when water demand can no longer be satisfied due to a lack of freshwater resources (Srinivasan et al. 2012). Physical water scarcity results in the depletion of water resources for both humans and natural systems and causes important transitions in the exploitation of different water compartments, e.g., from surface to groundwater sources, or even water transfers between basins. When excessive human consumption of water resources occurs under these circumstances, it may cause significant pressures on aquifers and surface waters, producing adverse effects on water quantity (over-exploitation) and quality (nutrient excess, pollution and lower biodiversity), which is detrimental to economic development and even compromises human health.

6.3.1 Future risks for water security

The Mediterranean Basin is particularly prone to limited water security due to its semi-arid to arid climates, especially as most important economies, such as tourism development *(Section 3.1.2.3)* and intensive agriculture *(Section 3.1.2.2)* are heavily water dependent and critically vulnerable to water scarcity and stress (Barceló and Sabater 2010). Thus, water security is at severe risk in the Mediterranean Basin. This susceptibility to scarcity is caused by strong human pressures, under the form of overexploitation, for agricultural, urban and industrial water uses, together with reduced availability of water due to climate change. Many Mediterranean water bodies, aquifer systems in particular *(Section 3.1.3.4)*, show over-exploitation associated with high seasonal water demand, and suffer from salinization, particularly in coastal areas and regions of intense irrigation and soil degradation. High human water demands in the region concentrate when water availability is at the lowest and exhausted aquifers co-occur with transformation of watercourses from permanent into intermittent. An increasingly common scenario in river basins includes headwaters becoming intermittent or even ephemeral, while lowlands bear aquifers that are depleted or contaminated by either salt or pollutants (Choukr-Allah et al. 2017). Growing human demands for water are leading to rapid increases in the frequency and severity of water scarcity, where there is insufficient water to simultaneously support both human and ecosystem water needs (Bond et al. 2019). With climate change and increasing demand for food and commercial services due to a growing population with higher demands, such patterns will very likely increase dramatically (Iglesias et al. 2012).

6.3.2 Management approaches, governance, and adaptation for water security

Observed trends and projections for the future indicate a strong susceptibility to changes in hydrological regimes, an increasing general shortage of water resources and consequent threats to water availability and management *(Section 3.1.1.1)*. However, it must be clearly stated that current uncertainties in climate projections and subsequent impact models, a yet incomplete understanding of the impact of a climate change signal on economic mechanisms or the lack of an elaborate and integrated human security conceptual framework, are imposing strong limitations on water-related decision-making under climate change conditions *(Section 3.1.5)*.

Climate, demographic and economic changes are expected to have strong impacts on the management of water resources, as well as on key strategic sectors of regional economies and their macroeconomic implications *(Section 3.1.5)*. Such developments bare the capacity to exacerbate tensions, and even intra- and inter-state conflicts among social, political, ecological and economic actors. Meanwhile, it is widely agreed that effective adaptation and prevention measures need multi-disciplinary preparation, analysis, action and promotion of collaborative strategies.

The complexity of the water cycle contrasts strongly with the low data availability, which (a) limits the number of analysis techniques and methods available to researchers, (b) limits the accuracy of models and predictions, and (c) consequently

[43] https://www.swpwater.org/

challenges the capabilities to develop appropriate management measures to mitigate or adapt the environment to scarcity and drought conditions. The current potential to develop appropriate regional adaptation measures to climate change impacts suffers heavily from large uncertainties. These spread along a long chain of components, starting from the definition of emission scenarios to global and regional climate modeling to impact models and a subsequent variety of management options. Furthermore, the lack of awareness or understanding of the complex climate-resource-society dynamics often leads to inappropriate measures or no measures at all. Integrated water resources management is a holistic approach that focuses on both environmental as well as on socio-economic factors influencing water availability and supply, and seeks an efficient blend of all available conventional and unconventional water resources to meet the demands of the full range of water users, especially in agriculture, industry and tourism. However, the management approaches and solutions adopted, e.g., in form of decision support for specific water resources systems, are often highly specific for individual case studies *(Section 3.1.5)*.

An inventory of international, national and regional policies dealing with responses to climate change, water resources management, responses to hazards and disasters, and security in the region, is essential for proposing a suitable policy framework to integrate security, climate change adaptation and water management issues and specific recommendations for policy streamlining at the UN, EU, national and regional levels.

Political, economic and social factors seem to be more important drivers of water-related conflicts than climate-related variables *(Section 5.3.3.2)*. States and state-led adaptation play a prominent role in affecting human security: states can greatly facilitate adaptation, but policies are also prone to adverse effects. Adaptation can both increase and diminish water security for certain groups, although this depends to a great extent on factors such as power relations, marginalization and governance. There are also varying capacities of states to implement effective adaptation policies. Analyzing the political economy in an area or country helps to understand state-led adaptation. Impacts on key strategic sectors typically consider agriculture and tourism. These sectors show specific dependence on water security, which is of quintessential importance in the Mediterranean economy, with relatively high adaptation potential to strategic policies.

Most Mediterranean countries will likely face water shortages *(Section 3.1.1.1)*. This can have significant implications in terms of agricultural productivity, income and welfare. However, the water gap in the Mediterranean area will be affected by different external drivers. In northern Mediterranean countries, this will be due to increased temperature and decreased precipitation. Middle East and North Africa economies will likely find it difficult to put aside precious water resources for the purpose of environmental preservation. In southern Mediterranean countries, the growing non-agricultural water needs (induced by strong economic and demographic development) will be an additional challenge to water security, demanding management improvements in water efficiency. Innovations include highly successful efforts to increase water use efficiency. Smart metering, for example, is being deployed to improve accuracy in billing, evaluate consumption and increase users' awareness of their own consumption (Revolve Water 2017).

6.3.3 Case studies

Due to the already high and expected increasing pressure on water resources in the Mediterranean, the efforts to counteract water scarcity and establish water security are manifold in scope, action and scale. As the challenges can be very site-specific, and triggered by both natural and anthropogenic drivers in various constellations, significant uncertainties remain in identifying suitable programs of measures, which would be generally applicable for being independent of region and scale. Thus, related activities can be embedded anywhere from pan-continental to national levels, but often basin-scale and even highly localized programs and case studies are implemented. The range of measures *(Section 3.1.5)* includes water-saving technologies, such as new equipment in irrigation agriculture and households, often complemented by improved water efficiency (e.g., by means of adapted water management procedures), as well as direct measures to increase water availability through additional multi-scale storage solutions (ranging from cisterns to large reservoirs) or through the use of unconventional water sources stemming from recharging wastewater or seawater desalination. The latter may however, cause environmental concerns due to soil contamination or energy consumption (IWA 2012).

All these aspects can be useful components of an integrated water resources management approach (Choukr-Allah et al. 2012) *(Section 3.1.5.1)*. To date, there are several highly successful examples of such an approach, but negative case studies also exist. This highlights the prevailing need for further research and transdisciplinary collaboration to reach and maintain water security in the Mediterranean (Ludwig et al. 2011; Ludwig and Roson 2016; Saladini et al. 2018).

Several success stories of water security measures related to wastewater re-use experiments on local scale applications exist. The case of Oueljet El Khoder, Tunisia, is an exemplary effort, which succeeded in establishing a sound system for water re-use to provide reliable water resources for irrigation and ensuring sustainable conditions for the underlying aquifer. In this case, the collaborative project SWIM Sustain Water MED[44] has introduced a tertiary treatment unit including a slow sand filter alongside a monitoring and early warning system for monitoring the quality of the treated wastewater. The installations resulted in an increased rate of re-use of reclaimed water and an extension of the agricultural irrigation area.

A main challenge, however, is the fact that despite the evidence of water scarcity being felt by stakeholders and end-users, the role of climate change and the related future exacerbation of water stress is often ignored and not perceived as a key issue for water uses and water security (La Jeunesse et al. 2015), In the course of the CLIMB project[45], several circum-Mediterranean case studies (e.g., France, Italy, Turkey, Egypt and Tunisia) showed that the main response to increasing water demand in the Mediterranean region is a progressive externalization of water resources, with limits imposed by national borders and technological possibilities. This thinking, which does not consider climate change as a driving force, is not sustainable and prone to rising water conflicts.

6.3.4 Innovation

In recent years, great energy and investment has been placed in the modernization of installations and development of (sometimes integrated) water resources management *(Section 3.1.5)* (Cameira and Santos Pereira 2019). However, in many cases, these efforts seek to adapt to current state challenges and fail to consider the rising pressures in the light of climate change and growing domestic and industrial water demand. One of the expected consequences of climate change alone is a reduction in annual precipitation, paired with a very likely increase in rainfall variability and extremes *(Section 2.2.5)*. All of these factors contribute to increasing vulnerability and risk in potentially affected regions and can consequently jeopardize water security. Innovation is needed to reach beyond the current limitations of water resources management by introducing flexible mechanisms that not only include novel water (saving) technologies, but also build on targeted water system analysis and research *(Section 3.1.5.2)*. Important elements of these types of systems start with the (re-)establishment of environmental monitoring networks, composed of a dense in-situ observational network paired with operational remote sensing applications (e.g., for spatial drought monitoring, including vegetation status, soil moisture, water levels). Based on such regular time series of data products, spatially-explicit and process-based models can be built with sufficient predictive power to support long-term planning and decision-making to adapt to the impacts of a gradual climate and global change.

Great innovation potential lies in the development of regionally specified and flexible response schemes to water scarcity that reach beyond the state-of-art and provide integrated solutions for increased water efficiency by combining improved water-saving technologies (Wang and Polcher 2019) with the provision of unconventional water resources (e.g., by managed aquifer recharge or saline water for irrigation (Reca et al. 2018; Tzoraki et al. 2018)), to avoid water stress *(Section 3.1.5.2)*. It is further necessary to establish systems for short-term predictions of extreme events and seasonal forecasts that allow for extended reaction time of first responders (Haro-Monteagudo et al. 2017; Corral et al. 2019) and affected industries, such as agriculture (Martínez-Fernández et al. 2013; Kourgialas et al. 2019) or tourism (Hadjikakou et al. 2013; Toth et al. 2018). Water-sensitive urban design (WSUD) is approach to management that is starting to take hold in cities, although slow to catch on in the Mediterranean (Goulden et al. 2018). This paradigm is fueled by the interest in sustainable urban development and it aims to integrate best water management practices (many related to stormwater runoff), with mechanisms of urban planning. WSUD, developed in Australia, connects urban planning with stormwater management mainly for protecting groundwater in aquifers. In the United States, planners employ a similar approach, called low-impact development (LID), which focuses on maintaining a steady hydrological response (i.e., stormwater runoff vol-

[44] https://www.swim-h2020.eu/

[45] https://cordis.europa.eu/project/id/244151

ume and discharge rate leaving the spatial unit before and after development), but also seeks to view stormwater as a benefit to the environment, rather than only as a disturbance (Carlson et al. 2015). While both LID and WSUD aim to minimize the hydrological effects of urban development on the surrounding environment, WSUD puts more emphasis on maintaining a water balance that considers waterway erosion along with the management of groundwater, stream flows, and flood damage. In Israel, this approach has been considered and implemented, but mostly on a local, site-specific basis, through such practices as retention pools, but it has been less successfully implemented to curb such problems as increased coastal erosion (Portman 2018).

In order to have practical impact, a crucial element in this endeavor is to fully take into consideration the political and institutional dimensions of dynamically changing priorities in water governance. This can be supported by novel ways of public participation and knowledge sharing between institutions and researchers (Bielsa and Cazcarro 2014), which in combination could and should lead to the development of smart water grids and efficient water licensing and metering.

6.4 Agricultural drought

6.4.1 Future drought risks in agriculture

Agricultural drought occurs when soil moisture availability to plants has dropped to such a level that it adversely affects crop and pasture growth (Mannochi et al. 2004). The Mediterranean region stands out as one meteorological drought hotspot where drought severity has increased in recent decades (Spinoni et al. 2019) *(Section 2.2.5)*. Regarding agriculture, climate warming exacerbates the impact of meteorological droughts through the increasing evaporative demand (Quintana-Seguí et al. 2016). The analysis of climate model ensembles in the Mediterranean consistently projects future meteorological droughts that translate into stronger soil moisture anomalies (Planton et al. 2012; Orlowsky and Seneviratne 2013; Dubrovský et al. 2014; Ruosteenoja et al. 2018) *(Section 3.1.4.1)*. More recently, Rojas et al. (2019) showed that climate models project negative precipitation trends outside the natural variability in the Mediterranean region in the mid-century, in all RCPs. A 10 to 30% decrease in precipitation is expected as early as 2040, in particular causing drier winters in northern Africa, and summer drying in southern Europe.

Already under "low" global warming levels of 1.5°C and 2°C, the exacerbation of drought conditions in the Mediterranean will be unprecedented since the last millennium (Guiot and Cramer 2016; Samaniego et al. 2018) *(Section 3.1.4.1)*. Furthermore, as Mediterranean drought events also imply hot summers (Zampieri et al. 2009; Hirschi et al. 2011; Russo et al. 2018), they drive a positive feedback that again enhances the frequency and the severity of agriculture droughts, directly challenging both crop and pasture management (e.g., Saadi et al. 2015; Scocco et al. 2016). Both rain-fed agriculture and irrigated agriculture are vulnerable to drought (García-Garizábal et al. 2014), because the availability of irrigation water may become limited by several factors, including depletion of overexploited groundwater (Famiglietti 2014), competition for water due to the expansion of irrigated agriculture (Khadra and Sagardoy 2019) or conflict with other water usages (e.g., Gössling et al. 2012) *(Section 3.2.2.1)*.

6.4.2 Management approaches, governance, and adaptation for agricultural drought

Farmers, who have been historically exposed to variable climate conditions, such as in the Mediterranean region, tend to be more prepared to cope with climate change (Reidsma et al. 2009). When it comes to droughts, several options are considered for avoiding water-stress in crops/pastures. Two main strategies can be identified: either ensuring that the water requirements are fulfilled (e.g., Fader et al. 2016), or requiring less water by modifying the agricultural system and its management so that the crops/pastures can better endure drought *(Section 3.2.3.1)*.

Adjusting irrigation water supply to satisfy water requirements

Rapid solutions for satisfying increasing water requirements, such as expanding irrigated areas or increasing groundwater and/or reservoir pumping, only have short-term effects and are often not sustainable when they lead to decreased groundwater levels, as reported from many regions (see Richey 2014 for the groundwater depletion of the major aquifers of the MENA region) or when only limited surface reservoirs are available *(Section 3.1.2.2)*. This affects all competitive water users, including the environment, e.g., the wetlands in the Upper Guadiana Basin in Spain (Carmona et al. 2011). Other solutions include the deployment of improved irrigation and conveyance systems, which have a large water-saving potential (e.g., sprinkler or drip). In recent years, governments of a few Mediterranean countries have subsidized pressurized irrigation systems (Daccache et al. 2014). According to the study by Fader et al. (2016), the Mediterranean region could save up to 35% of water by implementing such irrigation techniques *(Section 3.1.5.2)*. Nevertheless, these techniques alone are insufficient to face the increasing water demand resulting from climate change, demography, and socio-economic change (Malek and Verburg 2018).

Increasing attention is being given to wastewater reclamation and re-use, with important projects developed in countries all over the Mediterranean Basin since the end of the 20th century (Angelakis et al. 1999). From different experiments, it appears that treated wastewater re-use in integrated water resources management systems may provide significant benefits for irrigated agriculture and could be implemented in most water-scarce regions (Kalavrouziotis et al. 2015) *(Section 3.1.5.2)*. Even the use of poorly controlled treated wastewater does not damage the agronomic quality of soils. It even increases the soil organic matter (Cherfouh et al. 2018). Consequently, it is possible to expect both potential agronomical benefits and improved water supply from wastewater management.

Desalination of seawater for irrigation has high costs and many negative environmental impacts (Sadhwani et al. 2005). Furthermore high-level desalination removes ions that are essential for plant growth (Yermiyahu et al. 2007). The above studies concluded that desalination facilities for irrigation need revised treatment standards. An alternative strategy looks at crop performance under deficit irrigation. Promising results indicate an enhancement of water productivity, leading to proportionally lower yield reduction than water deficit. Furthermore, in the case of tomatoes, fruit quality is improved (Patanè et al. 2011).

Reducing water stress

The development of intensive agriculture since the second half of the 20th century has changed soil properties in several ways, including change of structure, decrease in soil organic matter, and decrease in biological activity (e.g., García-Orenes et al. 2012; Aguilera et al. 2013; Morugán-Coronado et al. 2015). In addition, many arable soils with cereals are left bare for extended periods (Kosmas et al. 1997), and bare soil beneath the rows is also a frequent feature of industrial perennial crops (Gómez et al. 2011). Both aspects impact the soil hydrological cycle, i.e., the water resources for crops/pastures. First, besides increasing erosion (which has reached dramatic levels in some Mediterranean cropping areas), bare soils favor evaporation and intercept precipitation water less well than vegetated or mulched soil (Monteiro and Lopes 2007). Second, low organic matter content, tillage practices, and the decline of biological activities all imply soil structure changes such as porosity (Pagliai et al. 2004) *(Section 3.2.3.2)*. In particular, the micropore to macropore ratio is modified: the proportion of micropores, which are considered the most important both in soil-water-plant relationships and in maintaining a good soil structure (Pagliai et al. 1983), is decreased by tillage, with a significantly reduced capacity to store water (Lampurlanés et al. 2016). Since the end of the 20th century, these phenomena have been studied in the Mediterranean Basin, using experiments on the effects of conservation agriculture (no tillage / reduced tillage, cover crops / mulching) on the soil-water dynamics for most of the Mediterranean cropping systems. These strategies are particularly promising in dry areas, and their average effect on Mediterranean agro-ecosystems, including yields, is beneficial, especially during water-stressed periods, despite the existence of contradictory results that may occur for many reasons (Mrabet 2002; Álvaro-Fuentes et al. 2007, 2008; Mrabet et al. 2012; Tomaz et al. 2017) *(Section 3.2.3)*.

These adaptation strategies also have benefits for climate mitigation, since conservation agriculture emits less greenhouse gases and generally leads to soil carbon sequestration (Kassam et al. 2012; Aguilera et al. 2013; García-Tejero et al. 2020) (*Sections 3.2.3.2* and *3.2.3.3*). The net effect of this is still debated and clearly depends on other factors as well (Govaerts et al. 2009). There is also a finite time horizon as the agro-ecosystem soil carbon maximum capacity is often reached after a 20-50-year period (Lal and Bruce 1999). In any case, incentives from different institutions now exist in several countries in order to promote agricultural management strategies that rely on key principles of conservation agriculture (Calatrava et al. 2011). Water stress can also be reduced if several crops (or crops and flower/grass strips) are grown in combination on the same land, which may result in a deeper penetration of the roots into the soil. Such plasticity has been observed in vineyards with cover cropping, where the compensatory growth of the grapevine root system allowed the resources (e.g., water) of deeper soil layers to be exploited (Celette et al. 2008). In an agroforestry system mixing walnut trees and winter crops, the competition with the winter crops induces deeper rooting of the walnut trees (Cardinael et al. 2015). Besides revealing the adaptive capacity of plants, these agroforestry practices provide welcomed shade in summer in the Mediterranean Basin, which is beneficial for both crops and livestock (Sá-Sousa 2014). Agroforestry systems are multifunctional, currently re-discovered in temperate areas – only for the montado-dehesa system of the Iberian Peninsula, a savanna-like rangeland dominated by scattered Mediterranean evergreen oak trees, the positive role of the trees on the water balance has been shown since the 20th century (Joffre and Rambal 1993, 2006).

6.4.3 Case studies

Many studies on no tillage in the Mediterranean show that this practice has positive effects on the soil for keeping more water, therefore enhancing yields, especially in water-stressed years. A few studies on the similar positive effects of agroforestry are shown in *Fig. 6.1.*

6.4.4 Innovation

Mycorrhizal symbiosis

In the Mediterranean Basin, the alleviation of drought stress by mycorrhizal symbiosis has been studied for more than 25 years (Sánchez-Díaz and Honrubia 1994). Using soils of different Mediterranean locations, controlled experiments regularly report the beneficial effect of arbuscular mycorrhizal symbiosis for crops in drought conditions: Meddich et al. (2000) for clover, Ruiz-Lozano et al. (2001) for soybean, Marulanda et al. (2007) for lavender, Navarro García et al. (2011) for cane-apple bush, Armada et al. (2015) for maize (using also drought-adapted autochthonous microorganisms), and Calvo-Polanco et al. (2016) for olive among others. Field experiments confirm that mycorrhizal inoculation alleviates water deficit impact (e.g., in Hungary, Bakr et al. 2018), but we are not aware of such field studies in the Mediterranean.

Considerable progress has been made in understanding the role of arbuscular mycorrhizal sym-

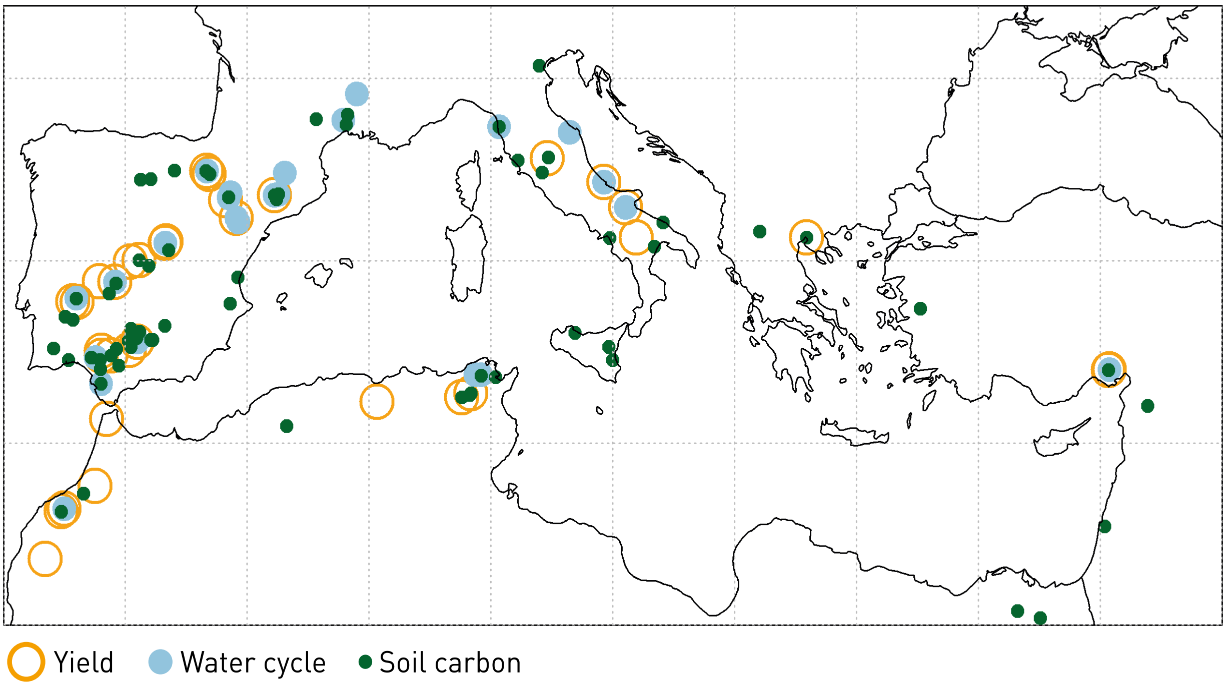

Figure 6.1 | Mediterranean sites where the impacts of innovative agricultural practices have been surveyed. These practices include "conservation agriculture", i.e., no or reduced tillage, organic amendments, cover crop, and two agroforestry sites. Dark green dots: sites where the impact of these practices on soil carbon have been measured, blue dots: sites where impacts on soil hydrology have been measured, orange circles: sites where the impacts on yields have been measured or surveyed.

biosis in reducing drought effects (Rapparini and Peñuelas 2014), but more studies are needed to elucidate the relevant mechanisms. Experiments are being carried out worldwide with different types of plants (Tyagi et al. 2017; Pavithra and Yapa 2018; Zhang et al. 2019), with particular focus on the efficient cooperation between nodulation and arbuscular mycorrhizal fungi (AMF) for legumes (Foyer et al. 2018). Understanding the AMF-mediated mechanisms that are important for regulating the establishment of mycorrhizal association and plant protective responses to unfavorable conditions will open up to new approaches to exploit AMF as a bioprotective tool against drought (Bahadur et al. 2019). Antagonistic interactions between barley and AMF have been observed under drought conditions, particularly at high AMF richness (Sendek et al. 2019) and suggest that unexpected alterations to plant-soil biotic interactions could occur under climate change.

Despite the benefits of AMF inoculation to crop production under water deficit, outcomes and challenges of AMF application for practical use in crop production may vary, e.g., in the event of possible colonization competition between the native populations of AMF in soils and the introduced symbionts (Posta and Duc 2019). Recent research has shown that compatible combination of AMF with other beneficial microbes such as plant growth-promoting bacteria offering synergistic effects on plant tolerance to stressful environments including drought stress is a promising perspective (Rahimzadeh and Pirzad 2017). Studies on quantitative trait loci involved in mycorrhizal plant responses to drought stress are needed for breeding programs to create new cultivars with a combination of drought-tolerant traits and AM benefits. Although biotechnology practices have already made the production of efficient arbuscular mycorrhizal fungal inoculants possible for the past 15 years (e.g., Barea et al. 2005), the farmers' awareness and acceptance of (relatively expensive) mycorrhizal inoculation remain low (Posta and Duc 2019). To conclude, while AMF inoculation in crop productions under water deficit seems promising, it has not yet proven its ability to be usable and successful for Mediterranean farming systems.

Composting

Composting technology is a modern technology that can produce a stable humus complex, used as high quality compost, providing plants with all required nutrients and micro-elements. Producers claim that the structure of this humus may increase the water holding capacity of soils by up to 70%, and have established composting facilities with organic farms in the Egyptian desert (Bandel 2009). However, results regarding water holding capacity development and enhanced resistance to drought are currently limited.

6.5 Wildfires

Mediterranean-type ecosystems are characterized by hot and dry summers and strong seasonality (Olson et al. 2001). Cool wet winters promote biomass growth and extended summer drought favors the regular occurrence of wildfires (Batllori et al. 2013). Historically, fires started by lightning during wet or dry storms, which can be very common in many Mediterranean-type ecosystems (Pineda and Rigo 2017). The geographic location of Mediterranean regions also benefits the frequency of strong wind events that further exacerbate fire activity. These ecosystems are dominated by fire-adapted vegetation resulting from a long evolutionary association with fire (Pausas and Keeley 2009), where usually crown and high-intensity fires largely prevail (Keeley et al. 2012a; *Section 4.3.3.1*).

Ever since prehistoric times, natural fire regimes have been altered by human activity in a multitude of ways, by modifying fuel structure, igniting new fires and extinguishing wildfires (Bowman et al. 2011; Keeley et al. 2012b). In highly populated areas, such as the Mediterranean Basin, it makes little sense to refer to a "natural" fire regime because the footprint of human dynamics has interacted with natural factors to mold fire regimes in time and space, and makes the characterization of a 'baseline' fire regime nearly impossible (Lloret and Vilà 2003). The alteration of ecosystems at unprecedented rates may lead to unidentified changes, making natural systems unable to persist within their natural variability regimes (Vitousek et al. 1997), potentially reaching no-return ecological states during this century (FAO 2013; Batllori et al. 2017).

6.5.1 Future wildfire risks

The present escalation of environmental changes is modifying fire regimes and producing new challenges for conservation management. In Mediterranean-type ecosystems of the European countries, afforestation linked to rural abandonment has occurred in recent decades *(Section 4.3.1.2)* and has shifted the systems to weather-limited fire regimes (Moreira et al. 2001; Pausas and Fernández-Muñoz 2012), in which the occurrence of fire-weather conditions drives fire activity (Pausas 2004), increasing the uncontrollability of fire events. The increase of adverse weather events associated with warming climate has stimulated an unsustainable fire regime perceived as a threat by society. Urbanization of rural areas during the second half of the 20st century has further modified fire dynamics, aggravating fire hazards due to the increase in ignition sources in these areas and an increased exposure of human activities to fire effects (Lampin-Maillet et al. 2011).

Direct human fire actions have also altered fire regimes (Bowman et al. 2011; Loepfe et al. 2011; Oliveira et al. 2012; Brotons et al. 2013; Chergui et al. 2017; Costafreda-Aumedes et al. 2017). Besides altering the spatial distribution of fuel, humans have also directly affected fire regimes by boosting anthropic ignitions and by suppressing fires with investments in huge fire-fighting structures *(Section 4.3.3.1)*. In European Mediterranean countries, fire management policies basically rely on the fire suppression principle, and the increasing effort made in this direction has strongly modified fire regimes (Brotons et al. 2013; Turco et al. 2013; Moreno et al. 2014; Otero and Nielsen 2017).

Climate change in the Mediterranean Basin is projected to increase summer heat wave events, extend fire seasons, increase yearly average temperatures and increase precipitation irregularities *(Section 2.2.5)* (Field et al. 2014). How these changes will impact wildfires is still being studied (Westerling et al. 2011; Batllori et al. 2013). While a warmer climate will upsurge fire activity by increasing water demand and decreasing fuel moisture, this increase in temperatures may also lead to a decline in ecosystem productivity and thus to an overall reduction of fuel biomass (Flannigan et al. 2009; Batllori et al. 2013), which can potentially counteract warming effects on fire activity. Climate change may also promote the occurrence of other disturbances (forest outbreaks, windstorms, non-indigenous etc.) that can result in new drivers of fire regime change *(Section 2.4.1.1)*. There is still a significant gap in the understanding and projection of future climate shifts and its impacts on ecosystems (Schoennagel et al. 2017; *Section 4.3.2.1*).

6.5.2 Management approaches, governance, and adaptation for wildfires

Changing fire regimes are now one of the most significant risks to natural systems and societies in places such as the Mediterranean Basin (Pausas et al. 2009). A deeper understanding of fire dynamics is therefore needed to enhance possibilities of successful biodiversity conservation strategies at the ecosystem level. In addition, a comprehensive understanding of fire regime patterns and processes will help to transform our societies within the resilience paradigm (Tedim et al. 2016). In recent decades, a rise in urbanization at the wildland-urban interfaces has led to an increasing number of fatalities (Moritz et al. 2014). The political response has been directed towards trying to eliminate fire from the system, with very limited success anywhere in the world (San-Miguel-Ayanz et al. 2013; Moritz et al. 2014; Archibald 2016; Tedim et al. 2016). There is an ongoing effort to promote development under which people are less vulnerable and more resilient to fire impacts *(Section 5.1.3)*.

The understanding on how the different drivers of change can further impact fire regimes is still limited (Flannigan et al. 2009; Westerling et al. 2011; Regos et al. 2014). However, there is no clear consensus on future land-cover change directions because they rely more on local economic drivers with high uncertainty in their long-term predictions (Rounsevell et al. 2006). In addition, the complex interactions of drivers, the cascading effects of sequential disturbances (Batllori et al. 2017), and the uncertainty of future conditions (Thompson and Calkin 2011) make the projection of future changes a major challenge. Fire research requires further tools and approaches that help to understand ongoing changes and provide solutions to help to make effective decisions.

Available evidence from recent decades show a steady increase in wildfire events leading to extreme wildfire events escaping from fire-fighting efforts, reaching acute fire intensities and often burning very large areas (San-Miguel-Ayanz et al. 2013) *(Section 2.6.3.3)*. Extreme wildfires have more significant consequences for societies and ecosystem properties than small fires (Adams 2013; San-Miguel-Ayanz et al. 2013; Tedim et al. 2013), and their occurrence is based on outstanding environmental conditions (San-Miguel-Ayanz et al. 2013). In European countries from the Mediterranean Basin, the appearance of these wildfires has been related to an expansion of forests interacting with increasingly hotter and drier weather conditions (Tedim et al. 2013). The high fuel loads accumulated in forests have resulted in intense fire behaviors (high flames, fire spotting capacity) that make them very difficult for fire-fighting brigades to control. Moreover, suppression systems often collapse when protecting dispersed human assets, diminishing direct fire suppression effectiveness. Under a climate change context, these extreme wildfires are projected to increase (Amatulli et al. 2013).

6.5.3 Case studies

Fire suppression strategies based on proactive opportunity search and advanced fire behavior (Castellnou et al. 2019) have been successful in some regions. However, increasing fuel loads and greater climate vulnerability make fire-fighting strategies prone to collapse in the event of extremely large or intense large fires, which has already happened in countries such as Greece and Portugal in recent years. Proactive systems may open the way for local stakeholders to participate in fire-fighting decisions (Otero et al. 2018). However, the key tractable factor behind potential reduction in future aggressive fire behavior is fuel availability. On these lines, different regions deploy prescribed fire techniques to decrease fuel loads in particular areas. However, contrary to other places with Mediterranean-type climate (such as Australia and California), deployment of prescribed fire over large tracts of land raises public concerns and is difficult to implement in Mediterranean countries, particularly in areas with a high percentage of private property (Fernandes 2018). In these cases, a combination of prescribed fire with other forest management techniques (such as using fuel for energy biomass) may be used (Regos et al. 2016). On the other hand, large tracts of conifer and eucalyptus plantations may increase the overall fire risk at the landscape scale, especially in comparison with mature native forests or more open farmland-dominated landscapes (Bowman et al. 2019).

6.5.4 Innovation

The key to sustainable, fire resilient landscapes is the development of sustainable socio-economic activities that allow local communities to thrive while ensuring low overall landscape risk and ensuring the persistence of other natural values (Smith et al. 2016). Such nature-based solutions to fire risk management (Duane et al. 2019) arise as an area where innovation, especially social innovation, is expected to develop in the coming years (Chergui et al. 2017). Technological innovation is also rapidly being introduced into strategic and operative fire-fighting, especially in relation to the use of remote sensors for data acquisition and remote control to predict extreme weather events leading to high-risk conditions conducive to intense fires (Peterson et al. 2017).

6.6 Soil erosion, degradation and desertification

6.6.1 Future risks for soils

Soil erosion, by water or wind, is the most widespread form of soil degradation worldwide (Panagos et al. 2017b). It is widespread in the Mediterranean region and includes sheet wash, rill and gully erosion, shallow landsliding, and the development of large and active badlands in both sub-humid and semi-arid areas (García-Ruiz et al. 2013). Soil erosion significantly alters the composition of soils, has a direct impact on the biogeochemical cycles that are responsible for supporting life on Earth and significantly reduces the ecosystem services and the economic systems that rely on them (Cherlet et al. 2018). The susceptibility of Mediterranean soils to erosion, degradation and desertification under changing conditions is exacerbated by a number of factors, such as deforestation, frequent forest fires, the cultivation of steep slopes and overgrazing (García-Ruiz et al. 2013) *(Section 2.4.1.2).* According to the United Nations Convention to Combat Desertification (UNCCD, 2004), Portugal, Spain, Italy, Greece, Turkey and Morocco have a significant problem with desertification because of the occurrence of particular conditions over large areas. International and interdisciplinary research initiatives have come to support this statement and have provided ample documentation that large areas of the European Mediterranean region are being increasingly affected by desertification, e.g., the EU MEDALUS, DISMED, MEDACTION, LEDDRA projects (Kosmas et al. 1999; Drake and Vafeidis 2004; Kepner et al. 2006; Sommer et al. 2011) *(Section 2.4.1.1).*

The assessment of future degradation and desertification risk and whether it can be reversed with land conservation and management practices, is affected by our ability to accurately set a baseline (Behnke and Mortimore 2016) or even decide on what constitutes an alarming rate. With the very slow rate of soil formation, any soil loss of more than 1 t ha^{-1} yr^{-1} can be considered as irreversible within a time span of 50-100 years. However, the concept of variable tolerable rates of erosion should be noted and requires further definition (di Stefano and Ferro 2016).

Numerous efforts to estimate current erosion rates have been reported in the literature, most commonly using empirical models (e.g., RUSLE) or physical process-based models (e.g., PESERA). A recent attempt to quantify soil erosion by water over the European region using the RUSLE model has reported very high soil loss rates for European Mediterranean countries of commonly over 50 t ha^{-1} yr^{-1}, mainly in southern Spain and Italy and to a lesser extent in Greece, Cyprus and France (Corsica) (Panagos et al. 2015). A more recent global modelling effort based on RUSLE by Borrelli et al. (2017) assessed the impact of land use change on soil erosion between 2001 and 2012. With regard to the Mediterranean Basin, it corroborated the previous findings and identified Morocco, northern Algeria, western Syria, Albania, Serbia, Montenegro and Bosnia Herzegovina as hotspots where erosion rates were predicted to increase according to a baseline scenario. Syria, Serbia, Croatia, Montenegro and Morocco were also projected to have increased soil erosion rates even with a conservation scenario. It is worth noting that soil erosion risk models contain erosivity and erodibility factors that reflect average-year rainfall. Therefore the currently available values for these factors may inadequately represent the more frequent and intense storms projected under most climate change scenarios (Jones et al. 2012). Moreover, Eekhout and de Vente (2019) have shown that applying different bias correction methods to contrasting Mediterranean conditions can lead to disparate soil erosion projections of either a future decrease or increase.

Other efforts have aimed at assessing the sensitivity of an area to degradation and desertification processes, using a system of indicators developed during the MEDALUS EU project (Kosmas et al. 1999), including soil erosivity, vegetation cover, climatic parameters (such as aridity), land use and land management. These studies have been applied in study sites throughout the Mediterranean, and have often identified hotspots of critical sensitivity to degradation and desertification (e.g., Lavado Contador et al. (2009) in Spain; Salvati and Bajocco (2011) in Italy; Symeonakis et al. (2014) in Greece; Kamel et al. (2015) in Lebanon; Boudjemline and Semar (2018) in Algeria, and Ait Lamqadem et al. (2018) in Morocco). Prăvălie et al. (2017) also applied this approach to the entire European Mediterranean for the years 2008 and 2017 and found widespread increases in sensitivity to desertification: the amount of territory with a high or very high sensitivity to desertification had increased, in less than a decade, by 177,000 km².

Adding to the complexity of assessing the future risks related to soil erosion and the reversibility of related degradation and desertification, climate change is expected to alter erosion rates in a complex, non-linear way. Rainfall changes (in either the intensity only or in the amounts as well), along with expected changes in temperature, solar radiation, and atmospheric CO_2 concentrations, will have significant impacts on soil erosion rates (Nunes et al. 2013; Li and Fang 2016; Zare et al. 2016; Zhou et al. 2016; Guo et al. 2019). Kirkby et al. (2004) describe a non-linear spatial and temporal response to climate change, with relatively large increases in erosion during wet years compared to dry years, and sporadic increases locally. However, the processes involved in the impact of climate change on soil erosion by water are complex, involving the abovementioned changes in rainfall amounts and intensities, the number of days of precipitation, plant biomass production and residue decomposition rates, soil microbial activity, evapotranspiration rates, and shifts in land use necessary to accommodate the new climatic regime (Nearing et al. 2004). Projections of changes in factors related to desertification indicate significant exacerbation of desertification risk in southern Europe and particularly in Spain, southern Italy, and Greece (Panagos et al. 2017a; Samaniego et al. 2018).

6.6.2 Management approaches, governance, and adaptation for soil protection

Soil erosion is greatly affected by human-environment interactions, most notably land use and land use changes. However, overly simplistic cause and effect approaches to what leads to degradation and desertification have now been abandoned (Cherlet et al. 2018) as the complex nature of non-equilibrium systems has been identified and acknowledged (Reynolds et al. 2007; Behnke and Mortimore 2016). A more integrated land management approach is currently driving policy-making, including the development and implementation of adaptive practices of sustainable land management. The World Overview of Conservation Approaches and Technologies (WOCAT) is a network that develops, archives, shares and disseminates sustainable land management knowledge to improve human livelihoods and the environment (Liniger et al. 2007), gaining broad appreciation from all involved stakeholders.

Sustainable land management approaches are continuously adapted in response to changing environmental conditions and human needs. From a list of hundreds of archived case studies of sustainable land management in the Mediterranean region, five types of measures are identified that can be taken to address land degradation (*Sections 3.2.3.2* and *4.3.3.3*): (i) agronomic measures: measures that improve soil cover (e.g., green cover), measures that enhance organic matter (e.g., manuring), soil-surface treatment (e.g., conservation tillage), and subsurface treatment (e.g., ripping); (ii) vegetative measures: plantation of trees and shrubs (e.g., live fences), grasses and herbaceous plants (e.g., grass strips); (iii) structural measures: terraces, bunds, banks, dams, pans, ditches, walls, barriers, and palisades; (iv) management measures: change of land use type, change in management/ intensity level, change in timing of activities, and control/change of species composition, and (v) combinations of the other four types (Liniger et al. 2007; Cherlet et al. 2018).

With regard to policy, at the moment, only a few EU Member States have specific legislation on soil protection. Soil is not subject to a comprehensive and coherent set of rules in the European Union. Existing EU policies in areas such as agriculture, water, waste, chemicals, and prevention of industrial pollution indirectly contribute to the protection of soils. However, as these policies have other aims and scopes of action, they are not sufficient to ensure an adequate level of protection for all soils in Europe[46]. A limited number of countries or Autonomous Regions have Soil Protection Plans (e.g., the Basque Autonomous Country (Landeta 1995), Italy (Law 97 of 1994)) while a much larger number have ratified the UNCCD and have prepared a National Programme to Combat Drought and Desertification or National Action Plan, namely, Algeria, Egypt, Greece, Italy, Lebanon, Morocco, Portugal, Spain, Tunisia and Turkey.

6.6.3 Case studies

Based on the WOCAT classification of measures that address soil erosion and land degradation, the following is a successful example of a structure measure from Spain. Rodrigo-Comino et al. (2017) assessed agri-spillways as a soil erosion protection measure in Mediterranean sloping vineyards in southern Spain. Their results showed a great capacity by rills to canalize large amounts of water and sediments, and higher water flow speeds and sediment concentration rates than typically found in other Mediterranean areas and land uses (such as badlands, rangelands or extensive crops of olives and almonds). They concluded that agri-spillways can be a potential solution as an inexpensive method to protect the soil in sloping Mediterranean vineyards.

Another example for sustainable land management comes from Italy, a case of a vegetative measure. Bagagiolo et al. (2018) studied the effect of controlled grass cover on water and soil losses in different rain-fed sloping fields in northwestern Italy. Rainfall, runoff and erosion variables were monitored in hydraulically bounded vineyard plots, where the inter-rows were managed with tillage and grass cover. The grass cover proved to be effective in decreasing runoff and soil losses during most of the events, reducing soil losses especially when intense events occurred (i.e., during summer). Their results also showed the fundamental role of contour-slope row orientation in reducing runoff and soil losses, irrespective of the adopted inter-row soil management approach.

6.6.4 Innovation

Land Degradation Neutrality (LDN) is a new conceptual framework, introduced by the UNCCD to halt the loss of land due to unsustainable management and land use changes (Cowie et al. 2018). Its purpose is to maintain the land resource base so that it can continue to supply ecosystem services while enhancing the resilience of the communities that depend on the land (Metternicht et al. 2019). The LDN framework is designed to apply to all land uses and all types of land degradation. To achieve LDN, countries will need to assess the effect of land use decisions and undertake measures to restore degraded land so as to compensate anticipated losses (Cowie et al. 2018). The UNCCD suggests that countries should consider the social, economic and environmental outcomes of alternative land degradation and desertification mitigation options when planning LDN measures and should strive to engage relevant stakeholders. Some applications of the LDN framework have only just begun to materialize (e.g., in southeast Australia, Cowie et al. 2019), but none have yet been applied in Mediterranean countries or climates.

[46] https://ec.europa.eu/environment/soil/index_en.htm

6.7 Heat waves

Temperature extremes occur on different time scales and need temporally high-resolution data to accurately assess possible changes (IPCC 2012). Temperature is associated with different types of extremes. It is of importance to distinguish between maximum, minimum and daily mean, as well as between cold and warm extremes, as they have different impacts on human health (*Sections 5.2.3* and *6.2*), the physical environment (Section 2.3), ecosystems *(Section 4.3)*, and energy consumption *(Section 3.3)*. Increases in the intensity, number, and length of heat waves have been reported for Mediterranean summers since the 1960s (Kuglitsch et al. 2010; Efthymiadis et al. 2011; Lelieveld et al. 2012) *(Section 2.2.4.1)*.

6.7.1 Future heat wave risks

Future projections for the Euro-Mediterranean area have shown spatial heterogeneity in increases in the intensity, frequency and duration of heat waves *(Section 2.2.4.2)*. Major increases in warm temperature extremes are expected across the Mediterranean region (Jacob et al. 2014; Russo et al. 2015; Zittis et al. 2016; Pereira et al. 2017) including hot days (T_{max} >30°C) and tropical nights (T_{min} >20°C) (Giannakopoulos et al. 2009; Tolika et al. 2012). Larger increases in intensity and duration are projected for southern Europe where heat wave days are projected to increase 20-fold by 2100 (Fischer and Schär 2010). Other projections over the Mediterranean include dramatic increases in the frequency of hot temperature extremes and heat stress by the end of the 21st century *(Section 2.2.4.2)*. Cities in southern Europe are expected to face longer heat waves (Guerreiro et al. 2018), thus increasing their vulnerability to climate impacts and the need for costly adaptation measures.

Projected changes in the characteristics of future heat waves are related to increasing risks in several sectors. Intense and long heat waves are related to increased morbidity and mortality in Mediterranean countries, especially in cities where the built environment amplifies the exposure to heat (*Sections 5.2.2.8* and *6.2*). Increasing temperatures affect overall energy demand for cooling, while heat waves may also affect peak demand that is mainly provided by electricity (EEA 2019a). The largest absolute increases in electricity peak demand are projected for Italy, Spain and France (Damm et al. 2017). The tourism sector plays an important role for the economic well-being and livelihoods of Mediterranean countries *(Section 5.1.1.3)*. Frequent heat waves may reduce tourist flows by the mid-21st century due to exceeded comfort levels (Hein et al. 2009) and could shift tourist demand outside the peak summer time (Perry 2003; Esteban-Talaya et al. 2005; Ciscar et al. 2009). Future increased extreme temperatures will increase the impact on transport infrastructure in the Mediterranean and will lead to damage to roads, rail, airports, and ports (Nemry and Demirel 2012; UNCTAD 2017; Vogel et al. 2017) with significant increases in adaptation costs (Nemry and Demirel 2012). High temperatures and drought will increase forest fire risk, which might lead to drastic damages in Mediterranean forests (Trigo et al. 2013; Gudmundsson et al. 2014; Turco et al. 2018) *(Section 4.3.2.1)*. High future temperatures and heat waves have a direct impact on crop growth conditions, crop productivity and crop distribution, agricultural pests and diseases, and the conditions for livestock production in the Mediterranean *(Section 3.2.1.4)*. These impacts will generate changing land-use patterns and will trigger economy-wide effects (Skuras and Psaltopoulos 2012). In southern Europe, yields for all the dominant (non-tropical) crops decreased by 5-60% because of climate change, depending on the country, the crop and the scenario *(Section 3.2.2.1)*. The combined effect of extreme heat events and shorter growing seasons will result in a loss of land suitable for agriculture (Fraga et al. 2016; Resco et al. 2016; EEA 2019b) in southern Europe (Section 3.2.2.1). Furthermore, the Mediterranean agro-climate zone is expected to experience pronounced increases in the areas affected by mild to strong heat stress, which will occur earlier and will impact winter wheat (Ceglar et al. 2019).

6.7.2 Management approaches, governance, and adaptation for heat wave risks

Reducing the direct impacts of extreme temperatures requires focus on information and preparedness associated with early warning (PPRD East 2013). The need for the implementation of early warning systems has risen since the 2003 summer heat wave (García-Herrera et al. 2010). Adaptation for heat waves in cities is a major challenge in design and costs estimation (Guerreiro et al. 2018). Prevention in the long term must further ensure that the vulnerability of the population and relevant infrastructure are reduced by improving urban planning and architecture (e.g., increasing the canopy cover in urban areas, cooling open public areas, adjustments in energy generation and transmission infrastructure), as well as through energy and transport policies (PPRD East 2013). Strategies are needed to reduce heat exposure of individuals and communities (especially vulnerable populations), to plan health and social services and infrastructure, and to provide timely information to the population (Future Earth 2019). Some of the adaptation measures for the projected changes entail fundamental, and expensive re-engineering of each city or water resource system. In the Mediterranean, significant adaptation measures to climate extremes, primarily in the form of structural protection measures, have already been implemented in the framework of the adaptation plans at the city, regional and national levels across the Mediterranean Basin.

6.8 River and pluvial flooding

6.8.1. Future flood risk

The Mediterranean region is characterized by numerous water courses with small and steep river catchments (Tarolli et al. 2012; Tramblay et al. 2019), although with notable exceptions, such as the Nile, Rhone, Ebro and Po rivers *(Section 3.1.1.1).* The steep orography surrounding the Mediterranean Sea favors the occurrence of intense precipitation events triggered by spatially confined convective processes (Amponsah et al. 2018), especially in autumn (Gaume et al. 2016) *(Section 2.2.5).* The resulting runoff can produce devastating flash floods in small river basins, i.e., less than 2,000–3,000 km² in size (Amponsah et al. 2018), especially where urbanized areas are located downstream of these small basins (Llasat et al. 2010; Gaume et al. 2016) *(Section 3.1.3.3).*

The magnitude and impact of floods vary significantly over the Mediterranean region, with more frequent and severe events in the western part (Llasat et al. 2010; Gaume et al. 2016). Some sub-regions in southwestern Europe, including Liguria and Piedmont in Italy, Cévennes-Vivarais-Roussillon in France, and Catalonia and the province of Valencia in Spain are particularly prone to extremely severe events, due to geographic and climatological conditions (Gaume et al. 2016). Floods in Morocco, Algeria and Tunisia are less frequent but they are often associated with high mortality, while European countries suffer the highest economic damages (Llasat et al. 2010).

Trends in annual maximum peak flow in European Mediterranean countries have been decreasing in the past decades (Blöschl et al. 2019). However, no significant trend in the frequency and magnitude of extreme floods has been found for the Mediterranean as a whole (Gaume et al. 2016), or for large regions such as Catalonia and southern France (Llasat et al. 2005, 2014; Tramblay et al. 2019), even though local increasing trends have been observed (e.g., Genoa urban area, Faccini et al. 2018; *Section 3.1.3.3*). Future trends in flood patterns still appear unclear, with different studies reporting contrasting results (Kundzewicz et al. 2017), partly because of the limitations of regional- and global-scale models in representing small catchments (Tramblay et al. 2019) (*Sections 3.1.4.1* and *3.1.4.2*: Floods).

6.8.2 Management approaches, governance, and adaptation for flood protection

Flash flood risk management presents several challenges with respect to other types of flooding processes. The triggering meteorological and hydrological processes are difficult to monitor with traditional hydro-meteorological networks, given the small spatial and temporal scales involved (Amponsah et al. 2018). Moreover, flash flood risk can be associated with other hazards, particularly in mountain settings (e.g., landslides and debris flows). This complicates the implementation of forecasting and early warning systems as well as the design of physical flood defense infrastructure (Borga et al. 2011). Preparedness strategies need to be structured in accordance with these and other characteristics, such as short to negligible warning lead times, immediate threat to life and properties requiring quick response times, as well as the need for refuges and safe places (Borga et al. 2011). This requires effective coordination of response management by authorities and public awareness.

Good practices in flash flood risk management reported in the literature and applied in several case studies include: post-event surveys to collect information on flood-generating processes and impacts (Kreibich et al. 2017; Amponsah et al. 2018), development of dedicated early warning systems

(EWS) based on gauge and radar networks, numerical weather and hydrological predictions (Corral et al. 2019), construction of check dams and reforestation in upstream areas (Kourgialas and Karatzas 2017), floodplain restoration and bank erosion protection (Kourgialas and Karatzas 2017; Cortès et al. 2018), suitable agricultural practices to retain water and reduce flood damage to crops (Kourgialas and Karatzas 2017), improvement of drainage systems in urbanized areas (Cortès et al. 2018), increased citizen awareness (Borga et al. 2011; Cortès et al. 2018; Faccini et al. 2018), emergency management plans (Kreibich et al. 2017), and viable insurance schemes for damage compensation (Faccini et al. 2018).

6.8.3 Case studies and innovation

At the European level, the European Directive on Floods (Directive 2007/60/CE, European Parliament 2007) regulates flood risk management plans, focusing on prevention, protection and preparation. The implementation of the Floods Directive has driven notable improvements, also in flash flood risk management. According to Kreibich et al. (2017), vulnerability to flash floods was greatly reduced in recent events in Italy and Spain as compared to similar events that occurred several decades ago, due to improved awareness, preparedness and emergency management.

Cortès et al. (2018) report that in the Metropolitan Area of Barcelona, the implementation of prevention measures such as constructing rainwater tanks, or the establishment of warning systems, decreased the impacts of flood events between 1981 and 2015. Nowadays, different flash-flood forecasting systems are present in Catalonia (Spain), Liguria (Italy) and Southern France (Corral et al. 2019). Notably, the European Flood Awareness System (EFAS)[47] provides different flash flood indicators (Raynaud et al. 2015; Corral et al. 2019), and has recently been extended to the entire Mediterranean Basin, therefore offering the first pan-Mediterranean forecasting system for river and flash floods. Finally, in Spain and France, dedicated national insurance schemes against natural disasters exist, which cover losses through economic compensation.

However, not all Mediterranean areas benefit from recent advances. Information on flood hazard and risk is missing or scarce in some southern and eastern Mediterranean countries (Llasat et al. 2010), as well as in small and ungauged catchments in Europe (Kourgialas and Karatzas 2017). Adaptation plans in southern Europe suffer from a lack of funding in rural and low-populated areas (Aguiar et al. 2018). Challenges are still present even in large cities. For example, the city of Genoa, Italy, is particularly exposed to flash floods due to its geographical location, meteorological conditions and dense urbanization with inadequate planning (e.g., reduced or culverted river network in the river valleys) (Faccini et al. 2018). While progress has been made in increasing citizen awareness and improving early warning systems, structural solutions (e.g., diversion channels, relocation of the most exposed properties) appear unfeasible due to the large areas involved.

6.9 Sea-level rise: coastal erosion and flooding, saltwater intrusion

6.9.1 Future risk associated with sea-level rise

Mediterranean mean sea levels are projected to rise by 21 to 27 cm by 2050, under RCP4.5 and RCP8.5 scenarios, respectively (Jackson and Jevrejeva 2016; Jevrejeva et al. 2016). By the end of the century, the mean sea level would range between 20 cm and 110 cm above the present level (1980-1999), depending on the greenhouse gas emission scenario and the modeling system *(Section 2.2.8.2)*. Such sea-level rise, combined with variations in extreme weather and thus waves and storm surges, will substantially increase the frequency of extreme events as the present day event of the century is expected to occur every 10 years by 2050 and at least yearly by the end of the century (Vousdoukas et al. 2018b). All the above changes are projected to expose Mediterranean societies to unprecedented levels of coastal flooding and losses. Without considering socio-economic development, a 6 to 8-fold increase in annual damage is expected by 2050 and at least 25 times more annual damage is expected by the end of the century if no further investments in coastal protection are undertaken (Vousdoukas et al. 2018a). When climate change projections are combined with socio-economic scenarios, expected annual damage is projected to rise by 90 to 900 times, depending on

[47] https://www.efas.eu/

the scenario. Adaptation in the form of dykes can cut damage costs in half, with countries such as France, Spain, Greece, and Italy having the highest damage costs in absolute terms (Hinkel et al. 2010), and Egypt and Tunisia facing the highest damages relative to their annual Gross Domestic Product (GDP) (Hinkel et al. 2012). Accordingly, Italy and France have the largest length of coasts where protection would be economically beneficial (Vousdoukas et al. 2020).

Most coastal regions globally are exposed on a daily basis to tidal water level variations of more than 50 cm, and ocean waves, which require wider active beach zones to act as a buffer against the ocean's forces. This is not the case in the Mediterranean, which is a micro-tidal area where a significant part of the coastline is not exposed to harsh marine storms *(Section 2.2.8)*. The above-mentioned characteristic makes the Mediterranean more susceptible to coastal hazards in view of climate change compared to other parts of the world. It is important to highlight that for many Mediterranean locations; the projected sea-level rise is of similar magnitude to the increase in sea levels during extreme events. At the same time, communities have developed lifestyles adapted to non-dynamic water levels, as several activities take place and infrastructure is located in close proximity to the sea (within few meters in many cases). This is also because apart from local-scale erosion, the coastline has been relatively stable for global standards with the exception of some cases of stronger shoreline retreat trends, observed in the Nile delta, Tunisia, Venice, and Albania (Luijendijk et al. 2018; Mentaschi et al. 2018).

Finally, interconnected hazards may exacerbate issues related to sea-level rise. For example, while the coastal environment encompasses particular characteristics distinct from general issues of water (such as shortages and drought) and precipitation (or lack thereof), there are numerous interconnections between water runoff, drainage and watershed management that are linked to hazards related to sea-level rise (O'Connor et al. 2009; Lichter and Felsenstein 2012; Portman 2018). Such hazards may result in compound effects that can lead to non-linear increases in the magnitude of individual hazards.

6.9.2 Management approaches, governance, and adaptation for coastal protection

It is important to highlight that coastal erosion in Mediterranean countries has been primarily driven by human interference with natural processes *(Section 4.2.1)*. For example, inadequate coastal management practices and, most importantly, unregulated construction have been reported in several regions (ERML 2012; de Leo et al. 2017; UNDP 2017). A recurring problem is the reduction or depletion of terrestrial sediment supply, that would naturally feed sandy beaches, resulting from the construction of upstream dams (Poulos and Collins 2002) *(Section 4.2.1.2)*. Such examples include the Beni Khiar and Dar Chaabane coasts and the Oued El Kebir river (Imen and Souissi 2018), Lesvos Island (Velegrakis et al. 2008), and Rhodope, Greece (Xeidakis et al. 2006).

Coastal adaptation practices can be classified into the following broad categories: protect, accommodate, advance, and retreat. Under protection practices, societies tend to "hold the line" by installing coastal protection elements. Traditionally these were mainly "hard structures" such as breakwaters and seawalls (Lamberti and Zanuttigh 2005). Dykes are another potential flood prevention solution, but they are very rare in the Mediterranean, as they are more common in meso-/macro-tidal environments. The same applies for surge barriers, with the only example being the MOSE system in Venice (CVN 2019). Submerged breakwaters reduce wave energy and mitigate erosion and have also become common practice along the Mediterranean coastline (Tomasicchio 1996; Sancho-García et al. 2013; Bouvier et al. 2017).

"Soft-protection", in the form of beach and shore nourishment as well as dune or wetland restoration, has become a more common alternative to hard structures in recent decades, with many examples, especially in France, Spain and Italy (Hamm et al. 1998; Hanson et al. 2002). Lately there is a tendency towards Ecosystem-based Adaptation (EbA) *(Section 4.2.3.5)*, also referred to as "soft protection", using ecological features such as reefs and/or coastal vegetation as coastal protection elements. Among the few examples of EbA is the coastal protection service provided by the Étang de Vic coastal lagoon in France (Conservatoire du littoral)[48] and the coastal dune reconstruction at the natural protection area of the Bevano river mouth in Emilia Romagna (Italy) (Giambastiani et al. 2016).

Until recently, advances through land reclamation has been more related to the need for more space to accommodate human activities (Mentaschi et al. 2018), but is also being increasingly considered

[48] http://www.conservatoire-du-littoral.fr/siteLittoral/106/28-etang-de-vic-34_herault.htm

in the context of adaptation to sea-level rise. However, this practice is practically non-existent in the Mediterranean Sea. The same can be argued for accommodation i.e., increasing the resilience of infrastructure by making it less vulnerable to flooding. Recent studies have shown that flood fatalities have been reduced as societies are learning to live with flood hazards (Bouwer and Jonkman 2018), while there have been efforts to develop and implement Early Warning Systems for disaster risk reduction (Ciavola et al. 2011; Harley et al. 2011; Fernández-Montblanc et al. 2019). However, there are very few, if any, examples of large-scale efforts to develop flood-resilient buildings around the Mediterranean coastline. The same applies to the retreat option in which exposure to coastal hazard is reduced by removing assets and people from potentially vulnerable areas.

6.9.3 Case studies

Hard protection structures can be found all along the Mediterranean coastline and in most cases they contribute to sustaining a safe and functional coastal zone (Iskander et al. 2007; Becchi et al. 2014). However, as it has been already pointed out in other parts of the world (Cooper and Pilkey 2012), this comes at a price. Hard protection can alter nearshore sediment transport patterns and result in beach erosion. Such side effects have been observed in Greece and Cyprus (Tsoukala et al. 2015), Tunisia (Saïdi et al. 2012), and Egypt (Masria et al. 2015). In addition, hard structures can affect the nearshore ecology, as they can act as habitats for species which normally thrive in rocky shores (Munari et al. 2011). However such effects have been shown to depend on local conditions and not to be overwhelming (Colosio et al. 2007; Becchi et al. 2014).

There have been several beach nourishment projects along the Mediterranean coastline, some of which have been reported in the scientific literature (Hamm et al. 1998; Hanson et al. 2002; Masria et al. 2015) *(Section 4.2.1.1)*. These initiatives are ecologically milder but can still come with negative impacts (Colosio et al. 2007). For example, nourishment at Poniente Beach (Benidorm, Spain) has been shown to have caused the disappearance of the *Posidonia oceanica* meadows, which resulted in a strong beach erosion process (Aragonés et al. 2015). However, there are several studies which report that small-scale beach nourishments appear to be an eco-sustainable approach to combat coastal erosion (Borg et al. 2006; Danovaro et al. 2018). Geotextiles have been installed in several locations as a soft protection practice, but information on their performance is limited in the scientific literature with a few exceptions, such as the positive outcome in Lido de Sete, in France (Balouin et al. 2015). It is important to highlight that most of the literature shows that no universal solution exists and that robust planning and implementation is a prerequisite for any successful intervention.

6.9.4 Innovation

Risk and climate change adaptation efforts are inextricably linked. Having acknowledged risks, some countries have developed either "resilience toolkits" (e.g., US) or "adaptation toolkits" (e.g., Ireland) that address how civil society must prepare for hazards, with emphasis on coastal areas (Paterson et al. 2017; McDermott and Surminski 2018; Gardiner et al. 2019). Most Mediterranean countries are lagging behind in this respect. Recently there has been significant work on at least assessment of future risks pertaining to air, water, and sea (Navarra and Tubiana 2013). However, little has been done on the aspects of extreme hazards and the effects of climate change on society, which could encourage more resources (both human and financial) being dedicated to adaptation planning. Nevertheless, some examples of such actions exist. Countries such as Italy, France and Spain have established national and subnational initiatives on coastal adaptation and management[49]) (Losada et al. 2019) while multi-national initiatives such as the Bologna Charter[50] have introduced action plans for the protection and sustainable development of coastal areas in the region through e.g., the establishment of a network of coastal observatories.

At the same time, interconnections between different types of hazards need to be addressed in research, planning and management for adaptation. To some extent, such interconnections are recognized and have led to initiatives. One example is the DANUBIUS-RI (Bradley et al. 2018), which is a platform designed to support interdisciplinary research on rivers and seas by facilitating biogeochemical monitoring while also spanning various aspects of environmental, social and economic sciences. These types of initiatives will no doubt support projects and future risk assessments related to climate change.

[49] www.erosionecostiera.isprambiente.it

[50] www.bolognacharter.eu

There is still a lack of information on the risks associated with the economic, livelihood and cultural consequences of coastal change (Reimann et al. 2018b) at the regional scale that would encourage progress towards the international and transboundary cooperation needed to address these challenges among Mediterranean countries. Transboundary cooperation is particularly difficult in the deep-sea areas, far from national jurisdiction. In these areas, cooperation is voluntary, often temporary and malleable at best, and non-existent at worst, even though it is compulsory for EU Member States based on Directive 2014/89/EU. Beyond the EU Mediterranean space, cooperation is voluntary. Much more oversight, accountability and especially monitoring is needed internationally (Neumann and Unger 2019), particularly in the Mediterranean. With regard to climate change, the "Our Ocean" Conference series, which has a strong topical relationship with SDG 14, has adopted climate change as one of its six areas of action (others are: marine protected areas, sustainable fisheries, marine pollution, sustainable blue economy, and maritime security).

6.10 Seawater temperature anomalies and extremes

6.10.1 Future risk of marine heat waves

Marine heat waves are periods of extremely warm sea surface temperature that persist from days to months and can extend up to thousands of kilometers *(Section 2.2.7.1)*. Recently observed marine heat waves demonstrated the strong influence of extreme climate events on marine organisms, including mass mortalities and shifts in species ranges (Rosenzweig et al. 2008), but also economic impacts on fisheries and aquaculture *(Section 4.2.1.1)*. In coastal areas at regional scales, little is known about the propagation at depth of a warming signal detected in sea temperature surface conditions. This is due to the scarcity of continuous observational data sets over the long-term (>10 years) from surface down through the water column (+40 m depth). Analysis of in situ temperature data available from different coastal sites confirmed warming trends in deeper layers consistent with those reported for surface waters (Bensoussan et al. 2019a). Thus, the warming is not limited to the surface, but propagates into deep coastal water layers (up to 80 m depth). Importantly, this warming displays significant variability along the depth gradient depending on local thermal regimes and seasonal stratification dynamics (Garrabou et al. 2019a). Likewise, marine heat waves have been recorded along depths with different intensity and duration depending on the years and concerned areas (Bensoussan et al. 2019b). Sustained observation in pilot sites will provide important information to validate models and track subsurface warming trends.

Like their atmospheric counterpart, Mediterranean marine heat waves are expected to increase in intensity, frequency and duration under anthropogenic climate change *(Section 2.2.7.2)* (Coumou and Rahmstorf 2012; Oliver et al. 2018). Darmaraki et al. (2019) used ensemble set of fully coupled Regional Climate Models (RCMs) from the Med-CORDEX initiative and a multi-scenario approach of different representative concentration pathways (RCPs), where marine heat waves become stronger and more intense under RCP4.5 and RCP8.5 than RCP2.6 by the year 2100. Under RCP8.5, a long-lasting Mediterranean marine heat wave appears at least once every year. Therefore, future marine heat waves appear up to three months longer, about four times more intense and 42 times more severe than at present *(Section 2.2.7.2)* and will affect the entire basin, predominantly in the warm and dry season from June to October. The main trigger can be attributed to the increase in the mean sea surface temperature (SST) and the daily SST variability. However, there is a lack of information on future trajectories of temperature conditions in coastal waters (from surface to 50 m depth and beyond) mainly due to the lack of customized modelling for these hydrodynamically complex areas. The results that are available point to an unambiguous increase in mean temperatures and frequency of extreme events, consistent with results obtained at the regional level (Garrabou et al. 2019b).

Current and future climate change trajectories are considered one of the major concerns for the conservation of marine biodiversity (Hughes et al. 2017; Cramer et al. 2018). In the Mediterranean, observed warming is already significantly affecting marine ecosystems (*Sections 4.1.1* and *4.2.1*), resulting in two main impacts: i) the shift in species distribution (indigenous and non–indigenous) and ii) the occurrence of unprecedented mass mortality events (MMEs). Besides these major impacts, other effects associated with warming are being reported as well, such as species proliferation and changes in species reproduction timing and migration patterns (Otero et al. 2013). Overall climate change is already dramatically affecting the abundance and distribution of species as well as the functioning of ecosystems (Sala et al. 2011; Givan et al. 2017; Cramer et al. 2018). It is difficult to foresee with precision to what extent the current climate trends will affect marine ecosystems and key species in the Mediterranean Sea in the coming decades. However, recent studies indicate that an increased extinction risk for endemic fauna, loss of habitat complexity and changes in ecosystem configurations is occurring (Ben Rais Lasram and Mouillot 2009; Ben Rais Lasram et al. 2010; Sala et al. 2011; Azzurro et al. 2019; Montero-Serra et al. 2019).

Three main patterns in species distribution associated with warming are being observed: i) northward expansion are extremely clear for warm-affinity native species such as the bluefish, *Pomatotus saltarix* (Dulčić et al. 2005; Sabatés et al. 2012), whose Mediterranean distribution was historically restricted to the southern and eastern sectors of the basin (Whitehead et al. 1986); ii) distribution contraction of cold-water affinity species in the northern areas such as the sprat *Sprattus sprattus* (Margonski et al. 2010), whose populations have drastically declined since the 1990s in the northern Adriatic and the Gulf of Lion (Lloret et al. 2001; Grbec et al. 2002; Hidalgo et al. 2020), and finally iii) west-eastward expansion of non-indigenous warm-adapted species of tropical origin, which are expanding their presence in the Mediterranean (Raitsos et al. 2010; Azzurro and Bariche 2017; Azzurro et al. 2019), for instance the case of the rabbitfish *Siganus luridus* and *S. rivulatus*, which are rapidly expanding their distribution and increase in abundance at the expense of their native counterpart *Sarpa salpa* (Marras et al. 2015) (*Sections 2.5.1* and *4.1.1*).

6.10.2 Management approaches, governance, and adaptation for ocean warming

Monitoring marine heat waves leads to a better understanding of their development, drivers and characteristics. Monitoring of near-time sea-surface temperature based on satellite data is possible, while the use of oceanographic arrays could provide information about heat penetration in deeper ocean layers. In the Mediterranean Sea, "T-MEDNet" was created in 2010 to develop an observation network on climate change effects and to spread standard monitoring protocols on seawater temperature and biological indicators. To date, continuous, quality checked temperature series are available at >70 sites and different ocean depths (5 to 40 m; T-MedNet 2019). They also evaluate satellite-derived sea-surface temperatures to track Mediterranean marine heat waves in near real-time.

6.11 Ocean acidification

Ocean acidification acts together with other global changes (e.g., warming, seawater expansion) and with local changes (e.g., pollution, eutrophication) *(Section 2.2.9).* These simultaneous pressures and stresses lead to interactive, complex and amplified impacts for species and ecosystems *(Section 4.1.1.1).* Globally, a pH change of -0.08 has occurred, on average, in the acidity of the oceans since the industrial age began *(Section 2.2.9.1),* i.e. a 30% increase in acidity. If we continue on our present course, this will lead to a -0.46 increase by the end of the century *(Section 2.2.9.2),* representing a 5-fold increase in acidity (Kolbert 2014). The term "ocean(s)" here is inclusive, encompassing marine and brackish water systems, from the open ocean to coastal waters, with the latter reflecting the immediate interface of land activities affecting the ocean, which has numerous implications for both eutrophication and acidification.

One of the issues generally underlined regarding research, and management to some extent, is the problem of ocean acidification being overshadowed by other more immediate, tangible and high-profile issues affecting the marine environment, such as marine litter (Tiller et al. 2019) *(Section 2.3.2.3).* This is also true in the Mediterranean region where the marine plastic and marine litter issue is quite acute and where there are tangible and significant effects on economic well-being (i.e., tourism), health and well-being (Portman and Brennan 2017; Portman et al. 2019).

It is difficult to carry out long-term realistic manipulations of CO_2 levels, and therefore scientists have used areas with naturally occurring high CO_2 levels to forecast the effects of ocean acidification. In an elaborate census offshore of Naples, Italy, divers collected data around deep-sea volcanic vents to find out which species, habitats and processes are resilient to and/or adversely affected by ocean acidification. At several hundred meters from the vents, scientists observed seaweeds of different types, sea cucumbers and urchins (by counting both sedentary flora and fauna and observing the movements of creatures). Closer to the vents, they observed that the number of species dropped. As pH levels dropped in proximity to the vents (indicating higher acidity), macroalgal habitats were found to be significantly altered. Also, mollusks or limpets, which came close to the vents, exhibited dissolved shells (e.g., with holes in them) (Porzio et al. 2011). Similar work has also been carried out more recently at Mediterranean sea vents by Vizzini et al. (2019).

With regard to close-to-shore systems, there are high levels of uncertainty about how coastal ecosystems will be affected by rapid ocean acidification caused by anthropogenic CO_2, due to a lack of data. However, further study is needed to investigate whether the observed response of macroalgal communities can be replicated in different seasons and from a range of geographical regions for incorporation into global modelling studies to predict the effects of CO_2 emissions on the Earth's ecosystems (Porzio et al. 2011).

6.11.1 Future risk of ocean acidification

On a global level, not specific to the Mediterranean, some effects of CO_2 absorption can be explored by researching conditions with lower pH (representing greater acidity) in waters near hydrothermal vents (Portman 2016). Hall-Spencer et al. (2008) found that typical rocky shore communities with abundant calcareous organisms shifted to communities lacking scleractinian corals with significant reductions in sea urchin and coralline algal abundance. To our knowledge, this is the first ecosystem-scale validation of predictions that these important groups of organisms are susceptible to elevated amounts of pCO_2. Seagrass production was highest in an area at mean pH 7.6 (1,827 µatm pCO_2) where coralline algal biomass was significantly reduced and gastropod shells were dissolving due to periods of carbonate sub-saturation.

Some work in the Mediterranean region has translated expected changes in ocean chemistry into impacts, first on marine and coastal ecosystems and then, through effects on services provided by these ecosystems to humans, into socio-economic costs using economic market and non-market valuation techniques (Rodrigues et al. 2013; Peled et al. 2018). Initial evaluations suggest that the important sectors affected are tourism and recreation, red coral extraction, and fisheries (both capture and aquaculture production) (Rodrigues et al. 2013) *(Section 4.1.2.1).*

One way to assess the future impacts of ocean acidification, especially socio-economic impacts, is through the assessment of ecosystem services. A number of general studies have looked at the effects of climate change including acidification. This includes studies by Canu et al. (2015) for the general Mediterranean and by Peled et al. (2018) for the eastern Mediterranean in particular. The advantage to such approaches is that they estimate the monetary value of maintaining elements of the environment that have the potential to reduce acidification. The problem is incorporating these approaches into policy so that there is practical application (Portman, 2013).

One of the most harmful effects of acidification will be on fisheries, which are increasingly important and threatened in the Mediterranean Sea. Lacoue-Labarthe et al. (2016) contend that ocean acidification should therefore be factored into fisheries and aquaculture management plans *(Section 4.1.3.4).* Recruitment and seed production present possible bottlenecks for shellfish aquaculture in the future since early life stages are vulnerable to acidification and warming. Although adult finfish seem able to withstand the projected increases in seawater CO_2, degradation of seabed habitats and increases in harmful blooms of algae and jellyfish might adversely affect fish stocks (Lacoue-Labarthe et al. 2016).

6.11.2 Management approaches, governance, and adaptation for ocean acidification

One approach that has been applied to encourage actions that will counter acidification is that of ecosystem services assessment. This approach aims to encourage action by evaluating the costs of inaction. Peled et al. (2018) did such an evaluation for the Israeli Exclusive Economic Zone. One advantage to their approach is that they account for permanent and temporary carbon sequestration and the use of Social Cost of Carbon (SCC) values. Overall, they find that within the context of ecosystem services, the biological component within the oceanic carbon cycle acts as a sink, which in its hypothetical absence would cause higher levels of CO_2 outgassing back to the atmosphere, potentially leading to greater acidification once gases are reabsorbed (Peled et al. 2018) *(Section 4.2.2.2).*

Kelly et al. (2011) posit that ocean acidification can be curbed by focusing more attention on local and regional actions within terrestrial watersheds. Ramajo et al. (2019) and others have suggested that seagrasses may provide "refugia" from ocean acidification for associated calcifying organisms, as their photosynthetic activity may raise pH above the thresholds for impacts on calcification and/or limit the time spent below some critical pH threshold.

6.12 Non-indigenous species: marine, freshwater, and terrestrial

6.12.1 Future risks associated with non-indigenous species

Non-indigenous species may be a significant threat to biodiversity, economies and human health globally (Early et al. 2016; Tobin 2018) *(Section 2.5)*. Climate change and projected climate-driven biome and thermal niche shifts, along with increases in trade and mobility, are the main drivers of non-indigenous species expansion globally (Early et al. 2016) and in the Mediterranean.

Today, the highest numbers of non-indigenous species have been recorded in high Human Development Index (HDI) and economically developed countries, which are also able to collect the most information and mobilize the best efforts to manage them (Early et al. 2016). Studies show that countries which are the biggest agricultural producers (such as China and the United States) could be the main potential sources of non-indigenous species and experience the largest negative impacts from future non-indigenous species introductions (Paini et al. 2016).

Future trends in geographical distributions of non-indigenous species intrusions are likely to differ considerably from current patterns *(Section 2.5.1.3)* (Early et al. 2016). Although the level of non-indigenous species will remain high in developed countries in the coming decades, they will increase substantially in developing countries where biodiversity may be high but capacity to manage non-indigenous species is low. Developing countries, especially Sub-Saharan African countries, could be the most vulnerable to non-indigenous species expansion (Paini et al. 2016). In such places, non-indigenous species will increasingly threaten human livelihoods.

Water-borne infectious diseases are strongly associated with freshwater non-indigenous species that are linked to changes in environmental conditions produced by climate change (*Sections 5.2.3.3* and *5.2.3.4*). Some pathogens including West Nile Virus, dengue, yellow fever virus, chikungunya fever virus, malaria sporozoan protists, filariasis and dirofilariasis nematodes, require aquatic arthropod vectors that are extending their range due to climate changes, at least on the northern rim of the Mediterranean *(Section 5.2.5.4)*.

The number of non-indigenous plants (Doblas-Miranda et al. 2017) in the Mediterranean Basin seems to be lower than in other European regions (Vilà et al. 2007; Gassó et al. 2012), probably due to environmental constraints, the long history of anthropogenic disturbances and the lower economic development of the region until recently (Castri et al. 1990; Vilà and Pujadas 2001). With regard to non-indigenous, the first vertebrates established in the Mediterranean Basin date back from the Neolithic period, although there has been an extraordinary increase in the rate of introduction of non-indigenous species since 1850 and especially in recent decades (Genovesi et al. 2009). Establishment success seems to be higher than in other Mediterranean-type climate regions of the world, at least for birds (Kark and Sol 2005). However, information related to non-native terrestrial invertebrates is largely unknown (Roques et al. 2009).

Introduction patterns of non-indigenous species differ considerably amongst groups, although they tend to mostly occupy anthropogenically modified habitats *(Section 2.5.2.1)*, while contrary to other regions of the world, natural and semi-natural woody habitats are relatively resistant to non-indigenous species (Vilà et al. 2007; Kark et al. 2009; Roques et al. 2009; Arianoutsou et al. 2010). As in other regions of the world, the increase in the establishment of non-indigenous species in the Mediterranean Basin will continue due to the increasing rate of transport of goods and people. Delays in the management response therefore suggest that non-indigenous species will become of even greater concern in the future. Currently, the information available on non-indigenous species in the Basin is not complete and the number of non-indigenous species across taxonomic groups is underestimated (DAISIE 2009). Detailed information on their distribution and ecological impacts is necessary to accurately determine the current status of non-indigenous species in the Mediterranean region.

The ecological and economic consequences of non-indigenous species introductions in terrestrial ecosystems of the Mediterranean Basin are beginning to emerge. Non-indigenous plants compete with indigenous species, decreasing local diversity and changing community composition (Vilà et al. 2006). Changes in ecosystem functioning have been less explored but include alterations in decomposition rates (Castro-Díez et al. 2009) and changes in soil carbon and nitrogen pools (Vilà et al. 2006). Even though the number of successful non-indigenous species seems to be higher in plants, the impacts of non-indigenous animals are not of lower magnitude. The presence of non-indigenous vertebrates poses severe threats to native biodiversity through competition for resources, predation and hybridization with native species, and economic impacts mainly through crop damage (Genovesi et al. 2009). Besides the lack of knowledge on the number of non-indigenous terrestrial invertebrates present in the Mediterranean Basin, most species established in Europe are known to be potential pests for agriculture and forestry products, while around 7% affect human and animal health (Roques et al. 2009). Their ecological consequences have received minor attention, although certain non-indigenous insect predators, such as *Linepithema humile* or *Harmonia axyridis,* are known to have a dramatic effect on native invertebrate communities (Angulo et al. 2011; Roy et al. 2011a, 2011b).

The Mediterranean Sea has a long history of anthropogenic activity and introduction of non-indigenous species and currently has a large number of them *(Section 2.5.1).* In recent years, the expansion of non-indigenous thermophilic species (that originally began started to enter the Mediterranean from the Indo-Pacific region during the 20th century) has been linked to climate-driven hydrographic changes. In the Mediterranean, non-indigenous thermophilic biota used to be restricted to the Levantine Basin, but are now found in the central and western basins (Occhipinti-Ambrogi and Galil 2010). The speed at which non-indigenous species are spreading in the Mediterranean Sea due to climate change is much faster than the actual increase in temperature, which is a great threat jeopardizing the future of biodiversity in the Mediterranean Sea (Raitsos et al. 2010).

Biodiversity hotspots are highly vulnerable to non-indigenous species given that many of the nations that harbor them have low management capacity (Early et al. 2016). This is likely to be the case in eastern Mediterranean countries that have experienced a 150% increase in the mean annual rate of species introductions since 1924. Studies of long-term data since 1924 of 149 warm-water non-indigenous species in the Mediterranean Sea show that the Lessepsian introductions has been amplified by the warming of the eastern Mediterranean Sea (Raitsos et al. 2010).

The freshwater ecosystems of the Mediterranean Basin are considered a biodiversity hotspot with a high level of endemism and small natural ranges of native fish vulnerable to extinction (Ribeiro and Leunda 2012). Aquatic non-indigenous species have the potential to cause cascading disruption in entire food webs, cause biodiversity loss and do economic harm (Thomaz et al. 2014). The spreading of non-indigenous species in Iberian Peninsula freshwater rivers is a potent threat to native freshwater populations. Studies in the southwestern Iberian Peninsula freshwater rivers show that the quantities of non-indigenous species were the best forecaster of the decline of native fish species (Hermoso et al. 2011). In addition, the risk of exotic pathogens is threatening European Mediterranean countries through a continued introduction of non-indigenous disease vectors and changing climate and environments (Medlock et al. 2012) *(Section 2.5.2.3).*

STAGE OF INTRODUCTION	STRATEGY
ARRIVAL	• Risk Analysis • International Standards • Inspection
ESTABLISHMENT	• Detection • Eradication
SPREAD	• Quarantine • Barrier Zone
IMPACT	• Suppression • Adaptation

Table 6.1 | Overview of stages of non-indigenous species introduction and potential management strategies (based on Lockwood et al. 2007; Tobin 2018).

6.12.2 Management approaches, governance, and adaptation for non-indigenous species

Patterns of introduction, magnitude and expansion of non-indigenous species are currently at the most rapid rate of change ever recorded in human history (Early et al. 2016). Only a minority of non-indigenous species succeed in establishing in their new locations and become a threat but those that do can result in billions of dollars in costs (Tobin 2018). As a result, management strategies continue to be an important element in global discussions on non-indigenous species. Central to best practice efforts in developing and implementing management frameworks is assessing the introduction stage of the species being addressed to identify the appropriate strategy *(Table 6.1)*.

6.12.3 Innovation

Effective management strategies often involve preventing the arrival of non-indigenous species from the onset. Advances in risk analysis have led to refined estimates of likely introduction pathways and the time at which the pathway is most likely to result in successful establishment (Gray 2016). This has led to more optimized allocation of limited inspection resources. Other advances in risk analysis include use of new technologies for detection and surveillance of non-indigenous species such as eDNA (Valentin et al. 2018) and utilizing bioeconomic models to formally consider ecological and economic links and dynamics that allow us to assess the costs of different management strategies (Lodge et al. 2016; Epanchin-Niell 2017). Finally, models of non-indigenous species distribution developed on their biological characteristics and climate suitability can potentially be used to predict susceptible areas (Mainali et al. 2015; Barbet-Massin et al. 2018).

6.13 Interactions of hazards, synergies and trade-offs between adaptation strategies and mitigation

The previous sections present the risks of the main hazards in the Mediterranean region, which are expected to increase in the future due to changes in environmental and societal conditions. Each section analyzes these hazards in isolation, without considering potential interactions. However, when two or more hazards occur at the same time, for example heavy precipitation coinciding with storm surge flooding, potential impacts increase due to compounding effects (Zscheischler et al. 2018), even in cases when none of the individual events is extreme. Also, cascading effects of hazards occurring in succession and overlapping temporally or spatially (de Ruiter et al. 2020), such as heavy precipitation triggering landslides, can lead to increased impacts (Gallina et al. 2016; Terzi et al. 2019). To cope with the impacts of compound and consecutive events, a holistic approach to future risk is needed that considers the interaction between hazards and identifies management and adaptation practices that can be successful in coping with a wide range of hazards. Such approaches build socio-ecological resilience, preparing society for future environmental change in a sustainable manner.

A large number of the management and adaptation measures discussed for a single hazard or sector present synergies with other hazards or sectors. For instance, the implementation of green roofs against heat stress *(Section 6.2.2)* additionally increases infiltration during flood events. Similarly, managing agricultural drought by using agroforestry systems *(Section 6.4.2)* increases shade thus decreasing heat stress, decreases soil erosion due to a deeper penetration of roots, and has a positive effect on the water balance, which can counteract water scarcity. However, some strategies can lead to trade-offs with other hazards or sectors. While Ecosystem-based Adaptation (EbA) can be a successful strategy against sea-level rise-related hazards *(Section 6.9.2)* and can, at the same time, provide health benefits to the population, EbA measures have high space needs and are therefore only applicable to a limited degree in urban locations (Temmerman et al. 2013). Another example is the use of desalination plants for managing water scarcity *(Section 6.4.2)*, which can lead to severe soil contamination. Examples of potential synergies and tradeoffs between adaptation measures are presented in *Table 6.2*.

The majority of strategies discussed above have positive effects on mitigation. Water-sensitive urban design (WSUD), sustainable land management and EbA, and other strategies have the potential to enhance CO_2 sequestration due to an increase in biomass. Such primarily nature-based strategies manage and protect ecosystems and their functions. Nature-based solutions can increase socio-ecological resilience in a wide range of contexts as these strategies, along with the concept of ecosystem services, further help to raise awareness regarding the importance of ecosys-

ADAPTATION STRATEGY	HAZARDS: SYNERGIES (+) & TRADE-OFFS (-)	SYNERGIES (+) & TRADE-OFFS (-) WITH MITIGATION
URBAN PLANNING		
Green roofs	+ Reduces heat stress + Increases infiltration during floods + Health benefits	+ Increases CO_2 sequestration in biomass
Increase in canopy cover in cities	+ Reduces heat stress + Increases infiltration during floods	+ Increases CO_2 sequestration in biomass
Water-sensitive urban design (WSUD), e.g., retention pools	+ Counteracts water scarcity + Counteracts salt water intrusion + Counteracts soil erosion + Increases infiltration during floods	+ Increases CO_2 sequestration due to more open/green space
Hard protection, e.g., sea walls	+ Protects from sea-level rise impacts - Potential increase in river/pluvial flood risk due to damming effects	- Energy intensive production
NATURE-BASED SOLUTIONS		
Conservation agriculture	+ Counteracts agricultural drought + Reduces soil erosion	+ Increases CO_2 sequestration in soils
Agroforestry systems	+ Counteracts agricultural drought + Shade reduces heat stress + Deeper penetration of roots counteracts soil erosion + Positive effect on water balance	+ Increases CO_2 sequestration in biomass
Sustainable land management, e.g., green cover	+ Counteracts soil erosion and desertification + Increases infiltration during floods + Increases water storage capacity	+ Increases CO_2 sequestration in biomass
Prescribed fire techniques	+ Reduce wildfire risk - Difficult to implement due to high amount of private property	+ Avoid large wildfires and so increase CO_2 sequestration potential in biomass
Reforestation in upstream areas	+ Reduces river flooding + Reduces soil erosion - Increases fuel biomass for wildfires	+ Increases CO_2 sequestration in biomass
Ecosystem-based Adaptation (EbA)	+ Protects from sea-level rise impacts + Health benefits - High space needs: applicable in selected locations only	+ Increases CO_2 sequestration in biomass
ENGINEERED SOLUTIONS		
Desalination of sea water	+ Counteracts water scarcity - Soil contamination	- Energy intensive process
PUBLIC OUTREACH		
Early warning systems (EWS), e.g., the European Flood Awareness System EFAS	+ Warn against multiple hazards, especially extremes, e.g., wildfires, coastal and river flooding, heat stress	
Awareness raising through ecosystem service assessment	+ Potential to reduce ocean acidification + Increases EbA via ecosystem conservation	- Increases CO_2 sequestration in biomass (if ecosystems conserved)

Table 6.2 | Selected adaptation strategies discussed in this chapter grouped by type of strategy, along with synergies and/or trade-offs with other hazards/sectors, and climate mitigation.

tems as an adaptation strategy, with positive effects on human well-being (Keesstra et al. 2018; Seddon et al. 2019). On the other hand, a number of adaptation strategies are energy-intensive and their implementation may lead to an increase in greenhouse gas emissions. Examples are the use of desalination plants or the construction of hard protection measures against sea-level rise.

The potential synergies and trade-offs of adaptation strategies with mitigation illustrate the importance of developing integrated policies for responding to future risks that incorporate adaptation and mitigation strategies *(Section 5.1.3.1)*. This would allow synergies to be harnessed more strategically while, at the same time, avoiding potential trade-offs between mitigation and adaptation practices. In a study assessing adaptation and mitigation plans in European cities, Reckien et al. (2018) found that only a few Mediterranean cities have local climate plans that consider both mitigation and adaptation in a joint manner. These cities were primarily located in France, with a small number of cities in Spain. In most other European Mediterranean countries, the majority of cities have climate plans for mitigation only, very few for adaptation only, and some do not have any climate plans at all. Assuming that this finding can be transferred to southern and eastern Mediterranean countries, there is an urgent need for such local climate plans. Cities, in particular, need to become more resilient to environmental change as impacts will be disproportionally high in these locations due to the concentration of population and assets in combination with hazard-amplifying conditions (e.g., increased run-off through soil sealing, urban heat island effect (Rosenzweig et al. 2010).

A number of region-wide concerns and needs are raised across the chapter that, if addressed, can promote socio-ecological resilience and sustainable development in the entire region. Long-term monitoring data are missing in many parts of the basin, with particularly large differences in monitoring and reporting schemes between northern (EU), eastern, and southern countries of the region. There is also a need for advancing (climate) modeling techniques such as the representation of small river catchments, the short-term prediction of extreme events (e.g., heat, flooding), and improvements in seasonal forecasts. Furthermore, public participation in the development and implementation of management and adaptation strategies is important for their success. Stakeholders need to be involved in this process right from the start to increase local relevance and acceptance of the proposed strategies, thus facilitating implementation. Sharing and including local knowledge in the process is of prime importance in building a resilient society in a sustainable manner (Oppenheimer et al. 2019). Low-effort and low-cost strategies, e.g., promoting household-level adaptation, can play an important role in increasing resilience and coping with risk in the near future (Koerth et al. 2013b, 2013a).

Although national and local strategies are essential and successful in coping with risk and in increasing resilience, integrated management and adaptation approaches that treat multiple hazards in a holistic manner are required to address the above-stated concerns. Such approaches can be initiated in a top-down manner through region-wide policies such as the Barcelona Convention. The Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean, established in 1976, provides a suitable basis for devising Mediterranean-wide policies. It was updated in 1995 and sets the basis for the Mediterranean Action Plan that is part of the UNEP Regional Seas Programme. One of its goals is to promote integrated management of the Mediterranean coastal zone. Considerable efforts have been undertaken in recent years with the aim to facilitate basin-wide planning and management such as the Protocol on Integrated Coastal Zone Management in the Mediterranean (UNEP/MAP/PAP 2008), the Mediterranean Strategy for Sustainable Development 2016-2025 (UNEP/MAP 2016) and the Regional Climate Change Adaptation Framework for the Mediterranean Marine and Coastal Areas (UNEP/MAP 2017) *(Section 5.1.1.2)*. These policy documents explicitly state the need for developing climate-resilient cities, acknowledging the importance of ecosystems for climate adaptation and mitigation, and enhancing regional and cross-border cooperation to promote sustainable development in the region (Benoit and Comeau 2005; UNEP/MAP 2012, 2016, 2017).

Active participation in regional-to-global initiatives and networks concerned with building socio-ecological resilience can be an additional important step forward. The "C40 Cities" network is concerned with achieving the goals of the Paris Agreement and currently has six members from the Mediterranean region (Barcelona, Rome, Venice, Athens, Istanbul, Tel Aviv). The "100 Resilient Cities" network aims to increase cities' resilience to a wide range of hazards, including drought, extreme heat, sea-level rise, but also other societal challenges such as corruption, demographic change, and poverty. Currently, ten Mediterranean cities are part of the network, including six from the northern Mediterranean and four from the South and East. Such initiatives can foster knowledge exchange, provide funding for specific projects, and promote ambitious action against climate and environmental change.

Lastly, the transfer of scientific knowledge to policy-making needs to be facilitated, for instance with the help of policy briefs and so-called "resilience toolkits" (such as RISC-KIT for coastal resilience[51]) in order to support well-informed decisions. Similarly, knowledge transfer concerning environmental issues and sustainable development needs to be an integral part of the curriculum in primary and secondary education, therefore increasing awareness and establishing sustainable lifestyles as a social norm (Otto et al. 2020).

This chapter illustrates that future risks in the Mediterranean region will be determined by hazard characteristics (intensity and frequency) and by developments in socio-economic conditions that determine a society's adaptive capacity to cope with those hazards. The level of risk will largely depend on how soon and how effectively sustainable development is pursued. With the tourism sector being a large source of revenue in most parts of the region, transforming this sector will be particularly challenging. War and social unrest pose an additional, currently more pressing challenge in several countries in the Middle East and North Africa. These current developments may lead to a widening of the development gap between northern, southern, and eastern countries of the region. Therefore, developing joint, region-wide, and integrated management and adaptation approaches that treat multiple hazards in a holistic manner is of utmost importance for sustainable development in the entire region. Nonetheless, no one-size-fits-all strategy exists, and each measure needs to be tailored to the respective local conditions.

[51] www.risckit.eu

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Information about authors

Coordinating Lead Authors

Athanasios Vafeidis:
Christian-Albrechts University, Kiel, Germany

Lead Authors

Ameer Abdulla:
Global Change Institute, Centre for Biodiversity and Conservation Science, University of Queensland, Australia

Alberte Bondeau:
Mediterranean Institute of Biodiversity and Ecology (IMBE, Aix-Marseille University, Avignon University, CNRS, IRD), Aix-en-Provence, France

Lluís Brotons:
Forest Science and Technology Centre of Catalonia (CTFC), Solsona, Spain

Ralf Ludwig:
Deptartment of Geography, Ludwig Maximilian University of Munich, Munich Germany

Michelle Portman:
MarCoast Ecosystem Integration Lab, Technion - Israel Institute of Technology, Haifa, Israel

Lena Reimann:
Christian-Albrechts University, Kiel, Germany

Michalis Vousdoukas:
European Commission, Joint Research Centre, Ispra, Italy

Elena Xoplaki:
Department of Geography & Center for international Development and Environmental Research, Justus Liebig University, Giessen, Germany

Contributing Authors

Najet Aroua:
Polytechnic School of Architecture and Urbanism, Algiers/ Laboratory of Architecture, Urbanism and Environmental Design, Department of Architecture, University of Biskra, Biskra, Algeria

Lorine Behr:
Center for International Development and Environmental Research , Justus-Liebig-University in Giessen, Germany

Francesco Dottori:
European Commission, Joint Research Centre, Ispra, Italy

Joaquim Garrabou:
Institute of Marine Sciences-CSIC, Barcelona, Spain

Christos Giannakopoulos:
National Observatory of Athens (NOA), Athens, Greece

Guillaume Rohat:
University of Geneva, Switzerland & University of Twente, the Netherlands

Elias Symeonakis:
Manchester Metropolitan University, United Kingdom