Managing climate and environmental risks

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Chapter 4
Managing climate and environmental risks

Executive Summary

***Adapting to coastal flooding* {4.2.1}**

Except for some experiments on relocation and nature-based solutions, current coastal management typically implements high-cost engineering protection, with potential adverse impacts on coastal landscape and biodiversity and associated ecosystems *(high confidence).* Solutions implemented so far, such as the MOSE barrier in Venice, are addressing near-term risk and will reach soft limits during the 21st century due to ongoing sea-level rise *(medium confidence).* The lack of consideration of climate change and sea-level rise in coastal flood risk management creates risks of lock-ins and maladaptation in the future *(high confidence)*.

***Adapting to coastal erosion* {4.2.2}**

The efficiency of engineering protection to prevent erosion in the Mediterranean is decreasing due to sediment scarcity in coastal areas *(medium confidence).* Nature-based solutions, such as protecting Posidonia meadows and their dead leaves on beaches, are receiving more attention and are increasingly implemented, but not to the scale needed to prevent current risks due to trade-offs with other aspects of coastal management such as cleaning beaches for tourism *(high confidence).* The implementation of nature-based solutions and relocation are limited by the lack of space and financing in many locations. Current management of coastal erosion generally takes into account future sea level rise only to a limited extent *(high confidence).* More transparent communication and governance that consider potential lock-ins and opportunities resulting from the ongoing transformation of Mediterranean coasts could enable adaptation to future escalating erosion risks, avoiding short-term actions that may lead to maladaptation in the future *(medium confidence).*

***Managing coastal ecosystems' biodiversity loss* {4.2.3, 4.2.4, 4.2.5}**

Mediterranean coastal ecosystems are those most threatened should regional climate change accelerate at a rapid rate due to human pressures and limited possibilities to migrate *(high confidence).* Many Mediterranean terrestrial, freshwater and marine coastal species and ecosystems are characterised by high rates of endemism, and some are already reaching their adaptation limits due to repeated heatwaves causing mass mortality. Rising temperatures, eutrophication, deoxygenation, acidification, sea level rise and on-going human activities, such as habitat destructions, eutrophication, and overfishing will cause further decline of ecosystems in the coming decades *(high confidence).* Yet, biodiversity losses can be limited by adequate conservation measures and adaptation if climate change is kept below 1.5°C with no or small overshoot *(medium confidence)*.

***Reducing pollution* {4.3}**

Management proposed at different levels, at the source point of pollution and the receiving system, requires continued long-term monitoring, quantifying ecosystem quality using different indicators and adaptive recovery management plans *(high confidence).* In general, reducing pollution at the source point is more efficient than at the endpoint *(high confidence).* If this is not possible, in some situations, tertiary technologies (bioremediation strategies, biofiltration, use of technological innovations) offer rapid, but often costly solutions at a local scale *(medium confidence).* Overall, different management options for various pollution types in the Mediterranean, including solid, liquid, and gaseous waste, have been considered. They range from improving production and consumption practices and promoting eco-friendly waste management practices, accompanied by a variety of market-based instruments and legislation.

***Managing non-indigenous species* {4.4}**

Policies to address the risks posed by the presence of non-indigenous species include eradication initiatives, commercial exploitation and providing protected habitats for native species. All these strategies pose challenges, and their advance is not sufficiently documented. Adaptation and keeping climate change below 1.5°C (with no or small overshoot) can limit biodiversity losses *(medium*

confidence). Implementing restrictions on fishing through large and sustained no-take protected areas can increase the resilience of ecosystems to climate change and to the expansion of non-indigenous species *(medium confidence)*.

***Managing freshwater scarcity* {4.2.4}**

Observed adaptation to reduced water quality and availability often focuses on increasing water supply, for example through additional storage facilities *(high confidence).* To limit future risks of water scarcity, adaptation measures aimed at reducing demand are increasingly needed in addition to protecting or increasing water resources *(high confidence).* Adaptation limits will be reached above 3°C of global warming in the north-eastern Mediterranean and possibly earlier in the eastern and southern Mediterranean, with the risk of compromising autonomous adaptation by coastal populations to scarcity of terrestrial, freshwater, and brackish water resources *(high confidence)*.

***Enhancing science-policy interaction* {4.7}**

Engaging science in dialogue with policymakers, stakeholders, and citizens, strongly contributes to raising awareness and knowledge, as well as to building trust. The most promising opportunity for establishing science-policy dialogue is during the planning process. Turning stakeholders into partners through participation, engagement, and ownership of the plan is the best way to ensure the plan's implementation *(high confidence).* In addition, the process of preparing plans is a unique opportunity to establish permanent structures for science-policy interaction. Connecting these two worlds cannot happen spontaneously, without a dedicated and organised framework designed to meet the differences and to overcome barriers.

***Augmenting regional cooperation* {4.7.4}**

Regional examples (Mediterranean Action Plan (MAP), Union for the Mediterranean (UfM), MedECC), national experiences, sub-national advisory boards, and governance network analysis results provide recommendations for potential adaptation responses. Current challenges, such as the need for more data and existing deep uncertainties, suggest adoption of phased approaches and adaptation pathways.

4.1 Introduction

The Mediterranean coastal areas are exposed to a wide range of climate and environmental risks that can lead to significant pressures on human communities and ecosystems in the region. Such present and potential future risks add to already existing multi-stressors and can have direct economic and societal consequences. Managing these risks effectively requires considering the economic, socio-cultural, institutional, and technological contexts. To address and respond to these challenges, solutions and approaches that are based on a deeper understanding of these climate and environmental risks and the socioeconomic settings, as well as concerted efforts at national and regional levels are necessary.

This chapter intends to identify and examine different responses and management approaches that are used in Mediterranean coastal areas for coping with climate change and environmental risks. It assesses the potential of existing and prospective responses, using a wide range of criteria, and presents best practices across the Mediterranean region. The chapter begins by discussing adaptation to climate risks (including climate change) and then looks at solutions to pollution and non-indigenous/invasive species issues. This is followed by possible measures to reduce potential tsunami risks, then risk synergies (compound risks), and management considerations are examined along with residual risks and barriers to effective responses. Thereafter, the important research policy interface and means to improve the uptake of research results by policymakers are considered. The chapter concludes with a number of examples of institutions in the Mediterranean such as MedECC, United Nations Environment Programme / Mediterranean Action Plan (UNEP/MAP) and its Regional Activity Centres (RAC), Sea'ties initiative from the Ocean and Climate Platform, and examples of research policy interfaces at the regional/local level policymaking in Croatia (Coastal plans Šibenik), France, and Spain (Barcelona, Catalonia).

4.2. Adaptation to climate change

Mediterranean coastal regions are highly exposed to climate hazards. This is because communities have developed lifestyles adapted to non-dynamic water levels due to the micro-tidal environment (MedECC 2020). As a result, an extensive range of social and economic activities take place on the coast and infrastructure is located in very close proximity to the sea. Rapid socio-economic development along the coast (Reimann et al. 2018) in combination with climate change, primarily sea level rise (Ali et al. 2022), are expected to further exacerbate this high exposure to climate extremes such as storm surges, waves, and heatwaves. Direct impacts will include increased coastal flooding (frequency and intensity), coastal erosion, loss of wetlands (Schuerch et al. 2022), salinisation of groundwater and loss of agricultural land, warming and acidification of coastal waters, which may cause damage to infrastructure (including critical infrastructure), loss of life, and affect food security and biodiversity. The following sections briefly assess the current status of coastal adaptation in the Mediterranean region, with a focus on flooding, erosion, coastal ecosystems, and water.

Table 4.1 | Effectiveness, feasibility, co-benefits, and trade-offs of coastal adaptation measures in the Mediterranean to avoid intolerable climate change risks. The table summarises the assessment of *Section 4.2* and builds upon the IPCC AR6 WGII report (IPCC 2022a).

Categories of adaptation measures for each hazard		Current Implementation	Effectiveness up to 2050	Feasibility			Relation with other systems at risk			Type of adaptation limits up to 2050[1]	Confidence and assessment	
				Technological	Economical	Socio-institutional	Economical development	Human wellbeing	Ecosystems		Evidence	Agreement
Coastal flooding	Protection	•••	••	•••	North: ••• South: ••	•••	+/–	+/–	Eng.: – NbS: +	Soft	••	•••
	Acommodation	•	•	••	•••	••	+	/	/	Hard	•	•••
	Avoidance[2]	•	••	•••	/	•	+/–	+/–	+	None	•	•••
Coastal erosion	Protection	•••	••	•••	•••	•/••	+/–	/	Eng.: – NbS: +	Hard[4]	•••	•••
	Accomodation	•/••	/	•••	/	•/••	+/–	/	NbS: +	Hard[4]	•	••
	Managed realienement[3]	•/••	•••	•••	North: •• South: /	•/••	/	/	NbS: +	Soft	••	•••
Coastal ecosystems	Autonomus Adaptation (AA)	NA	•	NA	NA	NA	NA	NA	NA	Hard	•••	•••
	Measures supporting AA	•	••/•••[5]	•••	/	/	+/–	+/–	NA	Hard	•••	•••
	Technologies and innovation	•	••	••	/	••	/	/	NA	/	•/••	••
	Socio-intitutional adaptation	•/••	•[5]	••/•••	/	•/••	/	/	NA	None	•••	•••
Scarcity of coastal freshwater ressources	Increasing water supply	•••	•	•••	•/••	••	+/–	+/–	–	Hard	•••	•••
	Demand oriented adaptation	•/••	••/•••	•••	•••	•/••	+	+	+	Soft	•••	•••
	Improving water quality	•	••	•••	••[7]	•	/	/	+	Soft	••	•••
	Governance	•/••	•••[6]	/	/	•/••	+	+	+	Soft	••	••

Legend :

•••	High	+	Positive	Eng.	Engineering protection[8]
••	Medium	–	Negative	NbS	Nature based solutions[8]
•	Soft	+/–	Mixed	Soft	Softs limits to adaptation[8]
		NA	not appropriate	NA	Hard limits to adaptation[8]

1 Soft and hard limits to adaptation are defined as in the 6th Assessment Report of the IPCC.
2 Avoidance consists in establishing setback zones. It currently dominates adaptation responses to coastal flooding within the relocation/advance/avoidance portfolio of measures in the Mediterranean region.
3 Though less implemented than engineering protection, managed realinement dominates adaptation responses to coastal erosion within the relocation/advance/avoidance portfolio of measures in the Mediterranean region.
4 Due to lack of space and sediments to protect from erosion.
5 Depending on ambition: efficient measures include large marine protected areas without fishing, system change in the agriculture sector resulting in a deep and rapid decrease of intrants such as nitrates and pesticides).
6 This solution does not provide benefits if implemented alone, but it can enhance the effectiveness of other measures or become an enabler of transformational adaptation.
7 Depends on policies and economical incentives supporting practices favoring water quality.
8 See definitions in the 6th Assessment Report of the IPCC.

4.2.1 Coastal flooding

4.2.1.1 Protection

In the context of coastal flooding, protection refers to the implementation of coastal structures or the restoration of coastal systems in order to reduce flooding risks in human settlement areas. Analyses at regional and national scale have shown that protection can be cost-efficient around most urbanised low-lying areas in the Mediterranean (Hinkel et al. 2010; Lincke and Hinkel 2018) *(medium confidence).* Costs of protection account for up to 0.1 to 0.2% of the GDP in countries located in the southern and eastern Mediterranean region, including Cyprus, Greece, Libya, Montenegro, Morocco, and Tunisia (Lincke and Hinkel 2018).

Presently, prevention of coastal flooding in Mediterranean cities, ports and coastal airports typically takes place through coastal engineering protection *(high confidence),* including coastal infrastructure such as breakwaters, seawalls, barriers or mobile dams, mechanical wetlands and water management works (Zviely et al. 2015; Ciampa et al. 2021; Ali et al. 2022; De Vivo et al. 2022; Sharaan et al. 2022). However, engineering protection can have adverse impacts for coastal hydrodynamics and ecosystems *(high confidence)* (Masria et al. 2015; Schoonees et al. 2019). Coastal engineering protection can also be combined with nature-based solutions such as coastal wetlands and dune restoration or revegetation of the coastline, as well as with other infrastructure such as roads, as suggested, for example, in the Nile Delta (Sharaan et al. 2022).

However, most coastal protection addresses only current coastal flooding risks and has limited consideration of current and future sea level rise. Even the mobile barriers system MOSE (MOdulo Sperimentale Elettromeccanico, Experimental Electromechanical Module) in Venice (Italy), which is a large-scale project that has been implemented in response to more frequent chronic flooding, could reach soft limits to adaptation within decades, as the gates will be closed more frequently with continued sea level rise, reducing ship traffic and lagoon water exchanges (Lionello et al. 2021). Overall, there is *high confidence* that besides front-running cities and ports, the majority of cities and ports in the Mediterranean region have not started planning for coastal protection or any other adaptation strategies to future sea level changes (Olazabal et al. 2019; McEvoy et al. 2021; Reckien et al. 2023). For example, there is a limited number of ports with known coastal adaptation strategies in Spain and many coastal cities' adaptation plans do not refer explicitly to future sea level rise (Portillo Juan et al. 2022; Ruiz-Campillo et al. 2022).

4.2.1.2 Accommodation

Accommodation consists in reducing the vulnerability of assets. It can be implemented at the level of building and infrastructure, for example by elevating electrical devices or avoiding basements in flood-prone areas, at the level of coastal flood management units for example, in combination with nature-based solutions such as wetland and dune restoration, or at the levels of institutions or governance by setting up alert systems and emergency plans or insurance products (Oppenheimer et al. 2019).

There is *low evidence* for coastal accommodation in the Mediterranean region in the scientific literature, but *high agreement* that accommodation is considered by individuals and public policies and can be supported by climate services such as coastal flood modelling (Zviely et al. 2015; Durand et al. 2018; Samaras and Karambas 2021).

4.2.1.3 Relocation, avoidance, and advance

There is evidence of efforts to avoid further increase of urbanisation in low-lying areas in the Mediterranean region, including in France and Portugal. This avoids an increase in exposure, which in the long term may require relocation. Such avoidance is prescribed in the form of setback zones in the Protocol on Integrated Coastal Zone Management (ICZM) in the Mediterranean (UNEP/MAP and PAP/RAC 2008) and is included in legislation in several countries. Although few studies exist, setback zones steering development away from the floodplain appear to have the potential to significantly reduce the impacts of future coastal flooding (Lincke et al. 2020; Wolff et al. 2020).

Besides these efforts, there is *high agreement* but *limited evidence* that maladaptive land use planning is taking place, as shown by local coastal development strategies, which are often inconsistent with national adaptation targets, as exemplified in French Mediterranean coastal municipalities (Robert and Schleyer-Lindenmann 2021). For existing coastal settlements and assets, retreat in response to flooding is considered less than in response to erosion. Advance toward the sea in the Mediterranean region is taking place in Monaco, where space is limited, and substantial financial resources are available. The infrastructure, which forms a peninsula extending the harbour, was designed for a lifetime of 100 years and considered some sea level rise scenarios as well as ecosystem compensation measures (Crémona et al. 2019).

4.2.2 Coastal erosion and shoreline changes

4.2.2.1 Protection

In the context of coastal erosion and shoreline changes, coastal protection aims at stabilising the coastline at a fixed average position or at least within a defined buffer area. The vast majority of adaptation efforts in the Mediterranean region has consisted in engineering-based approaches, such as groynes and rip-rap *(high confidence)* (Van Rijn 2011; Pranzini et al. 2015; Jiménez and Valdemoro 2019; El-Masry 2022). The effectiveness and costs of these measures depend on the local hydro sedimentary context. Furthermore, they have created new management issues such as scouring of infrastructure, loss of habitat and recreational value, as well as needs to bypass infrastructure such as ports, as reported for example in Egypt, Israel, and Italy *(high confidence)* (Nourisson et al. 2018; Biondo et al. 2020; Bitan and Zviely 2020; Caretta et al. 2022; El-Masry 2022; see *Section 4.3*).

Sedimentary accumulation can be enhanced by repeated onshore artificial nourishment of beaches. There is evidence that beach nourishment can be applied at small scale without major damage to coastal ecosystems (Danovaro et al. 2018; Vacchi et al. 2020). However, the lack of sand resources in the Mediterranean can compromise the effectiveness and feasibility of this measure. Specifically, imported sand may not have the same granulometry as that of beaches, resulting either in quicker dispersion of fine sediments or in a decrease of beach amenities if sediments are too coarse or have different colours *(high confidence)* (Pranzini 2018; Asensio-Montesinos et al. 2020; Bitan and Zviely 2020; de Schipper et al. 2020; Pinto et al. 2020). Beach drainage systems have also been employed to counteract erosion. However, there is mixed feedback regarding their implementation in the Mediterranean and a lack of scientific studies to assess their effectiveness in different contexts (Fischione et al. 2022). With sea level rise accelerating, protection needs against erosion will increase (Sharaan and Udo 2020) which will put even more pressure on the limited sand resources available and push coastal protection adaptation to its limits *(medium confidence).*

Nature-based solutions consist in leaving space for sediments and ecosystems to favour coastal accretion. They are in general cheaper to implement and more cost effective than engineering structures (Narayan et al. 2016). One emblematic ecosystem offering beach protection services in the Mediterranean is the declining seagrass meadow ecosystem dominated by *Posidonia oceanica,* which form banquettes on beaches and protects them from erosion (Telesca et al. 2015). However, current management practices often consist in removing dead Posidonia leaves from beaches, at least during the summer season (Simeone et al. 2022). *Posidonia* beaches are now often perceived as negative for tourism despite their beach protection value and potential to store carbon, suggesting that a paradigm shift will be required to develop this solution, in addition to adequate protection of *Posidonia* meadows (Fourqurean et al. 2012; Telesca et al. 2015; Rotini et al. 2020) *(high confidence).* Other nature-based solutions, such as the rewilding seashores or enhancing river-coast connectivity (Sánchez-Arcilla et al. 2022) can receive public support, but their climate relevance is not always understood, which raises the need for more public awareness (Sauer et al. 2022). In general, the resilience of coastal wetlands is linked to the availability of accommodation space that can be created by nature-based adaptation solutions (Schuerch et al. 2018).

4.2.2.2 Relocation

Experiments of landward relocation in the Mediterranean region are limited by the lack of space in low-lying coastal areas and by the low social and economic feasibility of this option. For example, exploratory studies in southern France have resulted in only a few implementations such as a €55 million-managed realignment on the sandspit between Sètes and Marseillan between 2007 and 2019 (Heurtefeux et al. 2011; Rocle et al. 2021). Another relocation project has been implemented in Slovenia, where the coastal state road from Koper to Izola has been moved inland, and the coastal space is to be reused and rehabilitated (PAP/RAC 2021). The lack of implementation of relocation can be due to constraints such as existing infrastructure, population growth and geopolitics (Portman et al. 2012), as well as the lack of perceived urgency, resistance, and the complexity of decision-making when multiple stakeholders are involved. However, in the long term, relocation policies may become economically viable taking into account the local tourist economy and environmental benefits, the *likely* fall in prices of real estate at risk and the implementation of anticipatory systematic plans *(medium confidence)* (André et al. 2016; Dachary-Bernard et al. 2019; Rey-Valette et al. 2019).

Managing erosion includes measures aimed at sustaining the protection and recreational services of beaches (Jiménez et al. 2011). A combination of nature-based solutions and relocations can be used to create a buffer area within which the shoreline can evolve without damage to infrastructure, for example by replacing an agricultural area with a salt marsh (López-Dóriga and Jiménez 2020; Molina et al. 2020). This option is considered as a potential transformative adaptation coastal approach, for example in Egypt (El-Masry et al. 2022). The approach conserves beaches while accepting some shoreline evolution, which requires implementing setback zones, raising awareness, and engaging in participatory approaches with stakeholders (Jiménez et al. 2011; Masria et al. 2015; Ali et al. 2022) *(high confidence).*

In summary, relocation and managed realignment are effective and feasible options that are increasingly considered and used, but their implementation remains limited at present due to major barriers such as costs and incompatibility with local development priorities *(Table 4.1) (medium-high confidence).*

4.2.3 Loss of coastal ecosystems

4.2.3.1 Autonomous adaptation

In the context of ecosystem adaptation to climate change, autonomous adaptation refers to the response of species and ecosystems themselves, without human intervention. The potential of Mediterranean coastal ecosystems to adapt to climate change is jeopardized by terrestrial and infralittoral habitat fragmentation, destruction, loss and overexploitation of coastal marine resources, severe nutrient loads and pollution, and non-indigenous species that arrive mainly through the Suez Canal (IPBES 2018a; Kim et al. 2019; Ali et al. 2022; Aurelle et al. 2022). In the Mediterranean, autonomous adaptation of coastal ecosystems is further limited by the inability of marine, freshwater and island-terrestrial ecosystems to migrate northward or to higher altitudes to move to more suitable thermal conditions (Ali et al. 2022; Aurelle et al. 2022). In this context, limits to autonomous adaptation of endemic species have already been reached for diverse groups of marine species, including macroinvertebrates (e.g. *Cnidaria, Porifera, Bryozoa*), macroalgae, seagrasses and fish species, which have been affected by mass mortality events associated with marine heatwaves *(high confidence).* During the last two decades, the frequency, number of species affected, and the severity of impacts have increased, and local extinction events have been observed (Garrabou et al. 2019; Kim et al. 2019; Ali et al. 2022; Garrabou et al.2022). For example, between 40 and 75% of surveyed marine species were affected by yearly mortality events from 2015 to 2019 in the western Mediterranean Sea (Garrabou et al. 2022).

In the coming decades, heatwaves, droughts, salinisation, erosion or submergence due to sea level rise and ocean acidification are additional potential threats to beaches, wetlands, lagoons, and river, estuarine and marine ecosystems (Lacoue-Labarthe et al. 2016; Parmesan et al. 2022). This raises adaptation challenges for the coastal ecosystems themselves as well as for their associated services, including activities such as fishing and aquaculture (Azzurro et al. 2019; Ali et al. 2022). In conclusion, the effectiveness of autonomous adaptation of coastal ecosystems in the Mediterranean is low, and hard limits are increasingly being reached *(high confidence) (Table 4.1).*

4.2.3.2 Measures supporting autonomous adaptation

A range of approaches to support the adaptation of coastal ecosystems has been explored, experimented, or implemented in the Mediterranean, including measures supporting autonomous adaptation, technologies, innovations (including nature-based solutions), and socio-institutional adaptation.

Autonomous adaptation is supported by habitat protection, limiting human pressures, and area-based conservation measures. Such measures are implemented in the Mediterranean, but they are too limited in scale and ambition to curb coastal ecosystem losses *(high confidence)* (IPBES 2019; Ali et al. 2022). The effectiveness of current marine protected areas (MPAs) to support coastal marine ecosystem adaptation to climate change is limited due to the lack of surface areas with high levels of protection (no-take-no-use areas), a lack of representative networks ensuring species connectivity, the absence or poor implementation of management plans, and a lack of consideration of climate change in existing plans and MPAs design (Bednar-Friedl et al. 2022; MedPAN and UNEP/MAP-SPA/RAC 2023).

Habitat protection measures aimed at reducing eutrophication of coastal and freshwater ecosystems would require strong reduction of nitrogen use in the agricultural sector, a shift toward agroecology (IPCC 2022b), as well as improvements in water treatment plants (Malagó et al. 2019). Protecting Mediterranean lagoon ecosystems more efficiently would require careful ground and surface water management, including demand-reduction measures to limit the degradation or perennial and intermittent disappearance of water bodies as well as to restore quality freshwater and sediment inflows (Erostate et al. 2020; Parmesan et al. 2022). Because the implementation of these measures is limited in scale and ambition, limits to autonomous adaptation are being reached for an increasing number of species, habitats, and ecosystems (e.g. Mediterranean gorgonians, mussels, seagrass meadows, freshwater ecosystems, wetlands) (Rodríguez-Santalla and Navarro 2021; Ali et al. 2022), especially since 2015 for coastal marine ecosystems (Garrabou et al. 2022). Hard limits are projected to be increasingly reached, especially above 1.5°C Global Warming Levels (Ali et al. 2022).

To summarise, measures supporting autonomous adaptation could be effective with increased ambition and implementation, but an increasing number of hard limits will be reached for every increment of global climate warming *(high confidence) (Table 4.1).* Enabling autonomous adaptation of coastal ecosystems in the Mediterranean requires immediate action to stabilise climate change well below 2°C global warming *(high confidence).*

4.2.3.3 Technologies and innovation

Technologies and innovations supporting coastal ecosystem adaptation include coastal adaptation measures that consider or benefit coastal ecosystems, as well as active restoration and assisted evolution. While there is evidence that a greener design of coastal protection infrastructure such as groynes and breakwaters can benefit coastal ecosystems (Schoonees et al. 2019), coastal protection measures in the Mediterranean have had damaging impacts on coastal marine freshwater and terrestrial ecosystems as they reduce and fragment habitats (Sedano et al. 2021). Therefore, future coastal adaptation to sea level rise risks of flooding and erosion represents a significant threat for Mediterranean coastal ecosystems if coastal engineering approaches do not leave space for sediments and coastal habitats (Ali et al. 2022).

Active restoration actions involve direct human intervention supporting the recovery of ecosystems that have been degraded, damaged or destroyed. Active restoration is being experimented in the Mediterranean, for example, to curb the extensive loss of macroalgal forests or restore coastal wetlands (Mauchamp et al. 2002; Pueyo-Ros et al. 2018; Tamburello et al. 2019). These actions can support a global strategy that also includes a significant reduction of human pressures causing the decline of macroalgal forests (Cebrian et al. 2021). Managed aquifer recharge is another example of active restoration of aquatic ecosystems linked to groundwater, as is maintaining freshwater resources in coastal areas threatened by salinisation due to coastal aquifer overexploitation (Rodríguez-Escales et al. 2018; Dillon et al. 2020). However, the scale and ambition of current ecological restoration is too limited to support the recovery of habitats at relevant ecological scales.

Assisted evolution, which aims to influence the evolutionary trajectory of species, can be beneficial for Mediterranean crops, but its advantages remain largely unknown for most Mediterranean wild species (Aurelle et al. 2022). Assisted evolution raises ethical issues and risks and may not be necessary for species with high gene flows or dispersal ability, such as many trees and marine species (Aurelle et al. 2022). However, monitoring the genetic adaptation of Mediterranean wild species to warming would be useful to assess the potential and limits to autonomous adaptation more precisely.

To summarise, the use of technologies and innovations to preserve Mediterranean coastal ecosystems remains limited today *(Table 4.1).*

4.2.3.4 Socio-institutional adaptation

Socio-institutional measures supporting ecosystem adaptation include monitoring and educational activities as well as improved coastal and water management and strengthened governance, and use of local knowledge (Azzurro et al. 2019). Significant observation and knowledge gaps in Mediterranean coastal ecosystems prevent the conditions for climate-resilient coastal ecosystems from being created along the Mediterranean (Erostate et al. 2020; Soria et al. 2022; Vera-Herrera et al. 2022). For example, better monitoring of pollutants and nutrients that compromise the hydrology of Mediterranean coastal ecosystems such as wetlands and lagoons could support more careful management of agricultural activities and wastewater treatment plants and reduce eutrophication (Soria et al. 2022; Vera-Herrera et al. 2022). Educational activities can support the emergence of a shift toward more ecosystem-friendly practices, avoiding widespread activities such as beach cleaning and trampling that cause dune and intertidal ecosystem decline along Mediterranean sandy coastlines. Integrated coastal zone management is increasingly considering coastal ecosystems, owing to the implementation of European directives such as the water and marine strategy directives in the northern Mediterranean (Bednar-Friedl et al. 2022). This includes increased recognition by the tourism sector that its impacts on the Mediterranean coastal environment can damage itself, and that this sector would benefit from shifting to more sustainable practices (Drius et al. 2019).

However, despite these recognitions, current institutions have yet to succeed in establishing a socio-institutional context able to preserve ecosystems *(high confidence)* (Said et al. 2018; Ruiz-Frau et al. 2019; Erostate et al. 2020). Strengthening current institutions and governance structures that operate at various levels from local to Mediterranean Basin scales can provide significant benefits for the management of Mediterranean coastal ecosystems (Geijzendorffer et al. 2019; Ali et al. 2022). For the preservation of ecosystems, marine conservation science that considers functionality can broaden the scope of what is considered 'worth' protecting (Rilov et al. 2020). In addition to areas set aside purposely as marine protected areas, especially those in nearshore coastal waters, areas closed to human uses for reasons other than conservation could be considered. Referred to as Other Effective Conservation Measures (OECMs), actions taken in the past have resulted in areas that could be considered within networks of protected areas (Shabtay et al. 2018, Shabtay et al. 2019).

To summarise, socio-institutional adaptation is being implemented, but far from the scale needed to effectively address the challenge of coastal ecosystem adaptation *(high confidence) (Table 4.1).* Strengthening ambition in this area will involve reinforcing the institutions that manage and protect coastal ecosystems, as well as a political resolve and leadership to give higher priority to biodiversity protection than today.

4.2.4 Scarcity of coastal freshwater resources

Water resources are unevenly distributed across the region, and therefore adaptation needs to vary significantly depending on the hydrogeological and coastal water management context. There is *high confidence* that adaptation to reduced water availability is taking place in Mediterranean coastal areas. These adaptation options consist in increasing water supply, reducing water demand, improving water quality, and supporting measures and governance (Caretta et al. 2022).

4.2.4.1 Increasing water supply

Observed adaptation often focuses on increasing water supply, through measures such as water diversion and transfers, diversification of resources, creating surface reservoirs, favouring water-adapted agricultural practices, favouring managed aquifer recharge when water is more abundant, water reuse, and desalination (Ricart et al. 2021; Ali et al.

2022; Bednar-Friedl et al. 2022). While generally efficient, these measures raise significant social, environmental, and economic challenges in the Mediterranean coastal regions *(high confidence)* (Pulido-Bosch et al. 2019; Malagó et al. 2021). For example, many wastewater reuse plants lack decarbonised energy production (Malagó et al. 2021). Furthermore, the rejected brine from existing desalination plants can have adverse impacts on Posidonia meadows, as is the case in the Balearic Islands (Capó et al. 2020). Together with other activities affecting ecosystems negatively, such as trawling, this can favour non-indigenous species *(high confidence)* (Kiparissis et al. 2011; Xevgenos et al. 2021).

Surface water reservoirs are vulnerable to heavy droughts due to evaporation, and groundwater recharge or water diversion requires investments and a season during which water is more abundant (Vicente-Serrano et al. 2017). Some measures such as the integration of solar panels in surface water reservoirs may limit evaporation and provide benefits for irrigation (Kougias et al. 2016). The role of groundwater as a strategic resource during drought can be strengthened in some contexts (Pulido-Velazquez et al. 2020).

To summarise, there is evidence that adaptation aimed at increasing water supply in Mediterranean coastal areas is reaching soft to hard limits in many subregions, including the north-western Mediterranean (Lavrnić et al. 2017; Malek and Verburg 2018) *(Table 4.1)*. There is *high confidence* that increasing water supply should be combined with measures aimed at reducing demand and improving water quality will be increasingly required to manage water in a sustainable way in the coastal zones of the Mediterranean region (Bednar-Friedl et al. 2022). However, meeting water demand, in particular from the agricultural sector, will also require increasing water supply in Mediterranean coastal regions, including through adaptation measures that may receive poor to moderate public support such as wastewater reuse *(medium confidence)* (Lavrnić et al. 2017; Morote et al. 2019; Malagó et al. 2021; Ricart et al. 2021).

4.2.4.2 Demand-oriented adaptation

There is *high confidence* that adaptation measures aimed at reducing demand are increasingly needed to address water scarcity in Mediterranean coastal areas. Reduction can be achieved by improving irrigation, changing agricultural practices, improved urban water management, economic and financial incentives, the regulation of distribution, as well as migration or off-farm diversification. There is increasing recognition that these measures, especially those aiming to improve irrigation and reduce water demand for the agricultural sector, need to be implemented at a much significant scale than currently in order to manage water scarcity (Brouziyne et al. 2018; Harmanny and Malek 2019; Kourgialas 2021). For example, considering the whole Mediterranean region and not only its coastal zone, it has been estimated that improving irrigation could reduce water demand by 35% (Ali et al. 2022). However, some agricultural practices are also evolving toward maladaptation lock-ins. For example, avocado cultivation is expanding in the Mediterranean, although it is highly vulnerable to salinity and water scarcity, thus increasing adaptation needs (e.g. irrigation improvements, fertigation, precision agriculture) (Mentzafou et al. 2017; Portillo Juan et al. 2022).

4.2.4.3 Improving water quality

Climate change is projected to decrease coastal water quality in the Mediterranean coastal region due to accumulation of pollutants and nutrients during drought, sea level rise, and salinisation (Zhang et al. 2021; Caretta et al. 2022). For example, in the Nile Delta, sea level rise is projected to lead to the deterioration of water quality, with adverse impacts for coastal ecosystems and aquaculture. However, coastal water management plans able to address the challenge are still lacking (Shalby et al. 2020). Measures aimed at improving water quality include wastewater treatment, nature-based solutions and changes in agricultural practices. Wastewater treatment is implemented, especially in the north-western Mediterranean coastal subregion, but so far with considerable adverse impacts on coastal ecosystems (see *Section 4.3*). Nature-based solutions, such as favouring marsh accretion to reduce surface saltwater inflow into aquifers and estuaries, require space for biophysical processes, and there is *low confidence* that they remain feasible and efficient for high rates of sea level rise (Zhang et al. 2022). Transformation of the agricultural sector will be required to reduce pollutants and nutrients and limit their impacts on water quality (see *Section 4.3*). In a context of water scarcity due to drought, developing infrastructure, agricultural practices and ecosystem-based adaptation able to improve water quality can contribute to adaptation efforts but represents a transformative system change *(high confidence)* (IPCC 2022). Such a transformation of the water/agriculture/food nexus can bring substantial co-benefits, such as increased human health (Zuccarello et al. 2021), aquaculture easing (El-Mezayen et al. 2018) and healthier terrestrial and freshwater ecosystems (see *Section 4.3*).

4.2.4.4 Governance

Increasing water availability and improving its quality requires stronger governance, policy, institutions, including transboundary management (Möller et al. 2020), as well as drought early warning systems, climate services, education and training *(high confidence)* (Ali et al. 2022). Managing coastal freshwater systems in a sustainable way requires not only responding to the demand of humans and their activities but also preserving ecosystems and their services (Drius et al. 2019). For coastal ecosystems, this also requires considering the impacts of supply-oriented measures on salinity, which in turn requires data and modelling capabilities (Vallejos et al. 2015). Water management in the Mediterranean can become more efficient through strategic and forward-looking planning of the entire food-energy-water-biodiversity nexus, strengthening institutions, enhancing finance mechanisms and the dialogue among stakeholders and regions as well as sharing data *(high confidence)* (Markantonis et al. 2019). Upscaling successful bottom-up approaches can also provide benefits (Markantonis et al. 2019). Awareness and understanding of the magnitude of impacts are increasing but remain limited (Mastrocicco and Colombani 2021). For example, hard adaptation limits are projected to be reached below 3°C of global warming in the Mediterranean coastal regions in the sector of hydroelectric production. Addressing the challenge of water scarcity will require a holistic approach with clear objectives on water quality and quantity, as well as a willingness to cooperate *(high confidence)* (IPBES 2018b; Bednar-Friedl et al. 2022).

4.2.5 Acidification of coastal waters

Even moderate acidification of coastal waters involves drastic changes to coastal Mediterranean ecosystems (Linares et al. 2015). In the Mediterranean Sea, risks posed by acidification are due to greenhouse gas emissions and human activities and linked to the vulnerability of its calcifying organisms (Range et al. 2014; Linares et al. 2015; Hassoun et al. 2022). Local adaptation measures involve improved management of activities causing local acidification, such as limiting the use of nutrients causing algal blooms and eutrophication, improving water treatment, restoring seagrasses, and reducing other stressors to increase coastal ecosystem (Bindoff et al. 2022). However, these measures can have only a short-term and limited effect as long as global acidification continues. Besides reducing greenhouse gas emissions, adding alkaline substances to Mediterranean seawater (alkalinisation) to enhance its role as a natural carbon sink and reducing acidification have been explored, but impacts on ecosystems remain largely unknown (Butenschön et al. 2021). There is *high confidence* that stronger governance is needed to address acidification challenges in the Mediterranean region, but a lack of observations and research prevents the feasibility and efficiency of autonomous adaptation of ecosystems from being assessed (Hassoun et al. 2022).

To summarise, combating acidification requires two actions: drastic reduction of greenhouse gas emissions, and local measures, such as a better coastal water management and seagrass restoration, to reduce acidification locally.

4.3 Pollution management and solutions

Coastal waters are heavily influenced by pollution originating from numerous human activities, such as industry, agriculture, urbanisation, and tourism. These are mainly land-based point and non-point sources, which cause the continuous degradation of coastal ecosystems. The Mediterranean Sea is one of the most affected regions and subject to intense pressures related to various types of pollutants that alter the physical, chemical, and biological characteristics of its coastal ecosystems. Significant pollutants include substances, such as nutrients (Malagó et al. 2019), plastic litter (Llorca et al. 2020), metals (Agamuthu et al. 2019), Persistent Organic Pollutants (POPs) (Castro-Jiménez et al. 2021), Polycyclic Aromatic Hydrocarbons (PAHs) (Merhaby et al. 2019), and forms of energies, such as thermal energy and noise. Several tonnes of plastic waste are discharged daily in the Mediterranean Sea, municipal solid waste generation has been constantly increasing in the region in the past decade, wastewater treatment plants largely contribute to nitrogen discharges leading to eutrophication phenomena, while the presence of emerging contaminants from pharmaceuticals, cosmetics, flame retardants, and others, with unknown long-term costs, has been reported (UNEP/MAP and Plan Bleu 2020).

Mediterranean countries have committed to depollute the Mediterranean Sea based on the 'Horizon 2020 Initiative' under the Euro-Mediterranean Partnership (or the UfM, as it was later re-launched). This overarching objective prioritised management focus on municipal waste, urban wastewater, and industrial emissions (Spiteri et al. 2016), even though current developments seem to overtake these targets. To highlight this point, research on solutions at the coastal ecosystem level seem largely under-represented.

4.3.1 Municipal waste

As a result of the recent European Green Deal development (EC Secretariat-General 2019), the new Circular Economy Action Plan aims to promote changes so that by 2050 Europe becomes more use-resource efficient, with Municipal Solid Waste (MSW) management as a key objective, even though this constitutes a very complex task (Kolekar et al. 2016). MSW generally includes fractions of paper, plastic, rubber, fabrics, food waste, wood and yard trimmings, cotton, and leather. These are suitable for the Waste-to-Energy industry for alternative fuels, and power generation endpoints (Mata-Lima et al. 2017). Ranieri et al. (2017) propose that compost can be an ideal management method to be implemented widely in the south-eastern Mediterranean region where the organic fraction in MSW is high. Italy is among the top biowaste-generating countries in Europe and is a model paradigm for the rest of the Mediterranean countries to develop decentralised composting programmes to achieve the action plan targets (Bruni et al. 2020). Compost from MSW has been found to be an alternative nutrient source for agriculture under Mediterranean conditions (Leogrande et al. 2020; de Sosa et al. 2021) contributing to pollutant removal and circular economy, while ethanol production from the cellulosic content of MSW is also proposed (Faraco and Hadar 2011).

4.3.2 Wastewater

Extensive research has investigated the potential of treated municipal wastewater for recycling and reuse in the Mediterranean countries, where treated wastewater reuse in agriculture is a common practice and there is a significant interest in the long-term effects of treated wastewater on crops (Pedrero et al. 2010; Abi Saab Daou et al. 2021; Abi Saab Zaghrini et al. 2021).

Overall, wastewater constitutes a substantial environmental issue that affects the Mediterranean region. The high organic load with toxic characteristics and low biodegradability of these effluents causes pressure on recipient ecosystems. In particular, the management of Olive Mill Waste (OMW) has been prioritised to minimise environmental impacts, and olive mills have been obliged to treat or even substantially reduce their waste. However, there are technical challenges to achieving efficient treatment, since the compounds-rich composition of OMW is highly variable, and largely non-biodegradable (Roig et al. 2006; McNamara et al. 2008). The Fenton's process (based on the production of hydroxyl radicals via the decomposition of hydrogen peroxide by iron ions) has been examined as a suitable detoxification option for the Mediterranean environment (Domingues et al. 2018) and can be applied preceding biological treatment, as the effluents' biodegradability increases while toxicity is reduced.

An innovative technology tested in real-scale systems in the Mediterranean is Microbial Electrochemically Assisted Treatment Wetlands, which relies on the stimulation of electroactive bacteria to increase the degradability potential of urban wastewater pollutants (Peñacoba-Antona et al. 2022). An alternative proposal consists of the development of a wastewater storage lagoon, an anaerobic digester, and a landfill disposal system. However, EU directives prohibit wastewater disposal in landfills. Controlled application and appropriate pre-treatment system design for landfill stabilisation could provide a sustainable solution for urban wastewater effluents discharged in the Mediterranean region (Diamantis et al. 2013). Other experimental solutions for wastewater pollutant removal have been recently tested on small scales, such as the use of green roofs with different substrates and plant species for greywater treatment (Thomaidi et al. 2022), the use of magnetic particles to reduce phosphorus in treated wastewater (Álvarez-Manzaneda et al. 2021), and the retention of wastewater in seminatural ponds, together with the use of biofilters, to improve the processes of assimilation of nutrients (de-los-Ríos-Mérida et al. 2021). However, treated urban wastewater in the Mediterranean Basis mainly undergoes primary and secondary treatment targeted to remove biological oxygen demand, while tertiary technologies are rarely implemented (Frascari et al. 2018).

4.3.3 Waste discharge

Industrial discharge in the coastal waters of the Mediterranean Sea accounts for approximately 10% of nutrient inputs (UNEP/MAP and Plan Bleu 2020), but industries related to cement, energy, fertiliser, chemicals, and metals production are responsible for high atmospheric metal emissions, which can be deposited into aquatic systems via rainfall or enter coastal sites through basin influxes and run-off (UNEP/MAP and MED POL 2012; UNEP/MAP 2013). Pressures brought by industry to coastal and marine environments add to and interact with other types of pressures, generating a broad range of waste and pollutants.

On-site solutions addressing generic waste disposal are limited in the region and are mostly implemented at a small-scale, research level. For example, passive abiotic treatment of acid mine drainage (AMD) with phosphate mining residuals was investigated in a mine in Algeria, indicating that all phosphatic lithologies were efficient in the treatment of AMD, efficiently removing metals from all materials (Merchichi et al. 2022). In another example, the carbon footprint variations were assessed in Spanish dairy cattle farms after modelling different scenarios focusing either on changes in management or changes in the diet of cattle. The management scenarios included the increase in milk production, the change in manure collection systems, the change in manure-type storage method, the change in bedding type, and the installation of an anaerobic digester. On the other hand, changes in feeding strategies included the reduction of the forage concentrate ratio, the improvement of forage quality, and the use of ionophores. Results suggested that changes in management were more effective in reducing greenhouse gas emissions (Ibidhi and Calsamiglia 2020).

In addition to the above-mentioned industries with straightforward pollution potential, an important contributor to coastal pressures is tourism. The overall flow of tourism in Europe is concentrated on Mediterranean coastal regions. Tourism is associated with a high environmental footprint with extreme pressure in the ecosystem and coastal areas (Pirani and Arafat 2014; Zorpas et al. 2018). Today, the implementation of environmental management systems (EMS), such as EMAS (Eco-Management and Audit Scheme)[46], ISO 14001[47], Green Key[48], which have been accepted by the tourism industry (Voukkali et al. 2017; Zorpas 2020), promote eco-friendly waste management practices, including waste collection and transportation,

46 https://green-forum.ec.europa.eu/emas_en

47 https://www.iso.org/standard/60857.html

48 https://www.greenkey.global/

specific order requirements from suppliers, and some recycling from stakeholders (Voukkali et al. 2021). However, these practices need modernisation, further assessment, and cost-effective corrections.

The management actions described above, albeit on par with the European action plan, can be complex and costly to implement on large scales, and mainly address pollutant inputs at the generic waste level. Therefore, solutions applied or tested may overlook specific significant pollutants of coastal ecosystems, including emerging contaminants previously ignored.

In accordance with global trends, Mediterranean coastal areas receive excessive loads of nutrients due to the increased anthropogenic presence, from river fluxes and basin run-off, aquaculture farms and fertilisers, urban effluents, industrial waste, and airborne deposition (Karydis and Kitsiou 2012). Nutrient inputs are the key cause of eutrophic phenomena, with many adverse effects for the marine ecosystem, aquatic life, humans, and economy (EC 2010), which have become increasingly pronounced in the last decade around the Mediterranean coasts (Tsikoti and Genitsaris 2021). Environmental indicators for quantifying eutrophication impacts and water quality (e.g. the EU Water Framework Directive (WFD), Directive 2000/60/E) have been proposed and developed, although their integration into management strategies is challenging. According to the EU 'Nitrates' Directive (Council Directive 91/676/EEC) which aims to reduce nitrates inputs from agricultural sources, two management tools are promoted, namely the assignment of vulnerable and sensitive zones and the development of good agricultural practices, including crop rotation systems, and appropriate procedures for land application that consider the land slope, the period of applying fertilisers, and the proximity of water recipient systems. Ample information and data from monitoring programmes are available in the region, and solutions for nutrient input reduction are known and implemented globally. Management strategies in the Mediterranean do not seem to suffer from a lack of information and policies, but rather from lack of implementation of these policies.

In general, solutions at the source point focus on anthropogenic nutrient input decrease, especially on dual nitrogen (N) and phosphorus (P) control. Consequently, measures to reduce nutrient pollution have consisted in upgrading all wastewater treatment plans to increase nutrient removal by applying enhanced reduction of phosphorus and lowering the mineral fertilisation in agricultural fields by setting nitrogen surplus limitations without changing livestock and manure production (Grizzetti et al. 2021). Large-scale management actions focused on wastewater treatment systems and diversions of urban effluents in the South of France have improved the ecological quality of eight eutrophic coastal lagoons close to Montpellier (Leruste et al. 2016). Other actions have targeted passive restoration practices at the source, such as sewer network treatment in estuarine watersheds and cessation of aquaculture (Leruste et al. 2016). In addition, three strategies were considered for reducing nutrient inputs into the Mar Menor (south-eastern Spain), the largest hypersaline coastal lagoon of the Mediterranean Basin: (1) reducing the leaching of nitrates into the aquifer by improving irrigation practices; (2) developing effective tools for denitrification of nitrate-rich brine produced by on-farm desalination plants; and (3) treating polluted water via hydrologic networks, subsurface flow, and drainage ditches (Álvarez-Rogel et al. 2020). The use of artificial intelligence in desalination plant production systems can be an innovative and promising approach in order to anticipate local algal blooms and thus reduce the nitrogen and phosphate concentrations in the feeding waters (Alayande et al. 2022; Mohamed et al. 2022).

4.3.4 Plastic litter

The Mediterranean Sea is recognised as one of the sixth largest marine litter accumulation zones worldwide (Lebreton et al. 2012; Cózar et al. 2015; Suaria et al. 2016). Due to its semi-enclosed shape and its thermohaline circulation of only deep water leaving the basin, the exchange of water with the Atlantic Ocean is limited (Lebreton et al. 2012; Simon-Sánchez et al. 2022). In addition, a heavily populated coastline with highly developed coastal tourism and intense economic activity (30% of global marine shipping traffic) lead to approximately 17,600 metric tonnes of plastic litter entering the Mediterranean waters annually (Cozar Cabañas et al. 2015; Cózar et al. 2015; Suaria et al. 2016; Pedrotti et al. 2022). The impacts of this pollution are not yet fully understood, but marine litter arguably constitutes one of the most complex challenges of the Mediterranean region (Suaria et al. 2016; Fossi and Panti 2020; Fossi et al. 2020).

Due to its geographical location between three neighbouring continents, there is still no consistent approach to reduce plastic litter pollution, as the gap between politics, science, and society still complicates the joint design and implementation of effective mitigation measures (Lebreton et al. 2012; Gorjanc et al. 2020; Cantasano 2022). On a European level, the Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC) was initiated to develop uniform monitoring and mitigation strategies for oceans and seas within the EU, to achieve a Good Environmental Status (GES) by 2020 (Fortibuoni et al. 2021). The MSFD is described by means of target-linked descriptors, of which three of the descriptors are related to marine litter (Morseletto 2020). These targets include actions such as implementing waste prevention through law-enforcement (such as the EU ban on single-use-plastic items from 2021, Directive (EU) 2019/904), appropriate waste management, such as measures to avoid marine litter generation as well as monitoring measures to assess or track the effectiveness of the actions implemented (Gorjanc et al. 2020). Similarly, there are aspects such as governance responses like specific waste management practices, control systems and a circular economy (Morseletto 2020; Fytianos et al. 2021). Even if the GES could not be achieved by 2020 in the Mediterranean region, initial implementation attempts by the MSFD have filled existing knowledge gaps concerning, for example, beach litter densities and composition (Fortibuoni et al. 2021). As a result, understanding of the litter problem in the Mediterranean region has increased continuously due to a wide range of studies driven by the MSFD, the Barcelona Convention Plan for Marine Litter Management in the Mediterranean and the Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast (IMAP) (Morseletto 2020). The latter has fostered the cooperation of all Mediterranean member states since 2016. However, to date, most information on marine litter in the Mediterranean Sea remains spatially inconsistent and focused mainly on the north-western part of the Mediterranean Sea (Llorca et al. 2020; Fortibuoni et al. 2021). A first step in addressing this issue was the Marine Litter MED II project[49] initiated by the European Commission and executed for a duration of 36 months by the UNEP/MAP-Barcelona Convention Secretariat and MAP components (2020–2023) with a particular focus on southern Mediterranean countries. Acting together, all parties could contribute to effectively fostering preventative and reduction actions, technological solutions, as well as education and awareness-raising measures, in order to overcome existing knowledge gaps and support effective decision-making in the future (Fossi et al. 2020; Simon-Sánchez et al. 2022).

Plastic and microplastic waste can adversely affect not only aquatic ecosystems but also economies and societies dependent on such ecosystems. Managing (micro)plastic waste can be approached from short- and long-term perspectives. Short-term solutions include improving waste management, particularly in critical locations. These efforts should be supported by a variety of market-based instruments and legislation (Löhr et al. 2017).

4.3.5 Metals, persistent organic pollutants, and emerging pollutants

4.3.5.1 Metals

Although extensive research has been published on metals enrichment of coastal sediments in the Mediterranean (e.g. Okbah et al. 2014; Martínez-Guijarro et al. 2019; Nour et al. 2019; Stamatis et al. 2019), solutions at the source points are not yet well formulated.

Sediments act as storage pools that recycle toxic substances in the water column with severe ecotoxicological effects on aquatic species (Iamiceli et al. 2015), therefore ending contamination activities is the first step. One of the most characteristic examples is Portman Bay (Murcia, southeastern Spain), where the dumping of mine tailings during the second half of the 20th century until 1991 is considered the largest metal pollution case in the western Mediterranean Sea (Martínez-Sánchez et

49 https://www.unep.org/unepmap/what-we-do/projects/MarineLitterMED-II

al. 2017). Even after 15 years of stopped dumping activities, the Bay remained highly contaminated (Benedicto et al. 2008).

To reduce inputs (when the termination of pollution is impossible to implement), the introduction of constructed wetlands (CWs) between sources and natural aquatic recipient systems is a proposed approach for eco-remediation in the Mediterranean Basin. The role of plant composition of CWs for metals' uptake has raised lengthy debates with contradictory outputs that influence management choices (Guittonny-Philippe et al. 2014). For example, different modules of CW consist of a biotic network in which variable community levels, from microbes to macrophytes and plants, interact and form a depurative ecosystem. This ecosystem must be designed in its substrate and biological composition to address pollution by a specific group of metal contaminants. The selection and management of the biotic counterparts (e.g. cutting and harvesting plants, replanting, frequency and timing of actions) may affect the effectiveness of metal removal choices (Guittonny-Philippe et al. 2014). In addition, biochar has been found to reduce the leaching of heavy metals present in raw sewage sludge in Mediterranean soils, and subsequently positively affect run-off inputs to coastal sites (Méndez et al. 2012).

4.3.5.2 Persistent organic pollutants and emerging pollutants

Further concerns have been recently raised about the occurrence, transport and fate of Persistent Organic Pollutants (POPs) in coastal systems (e.g. Barón et al. 2014; Barón et al. 2015; Lorenzo et al. 2019). Some of the POPs with increased concentrations in the Mediterranean, for which solutions are investigated include Organophosphate Flame Retardants (OPFRs), Perfluoroalkyl Substances (PFASs), and Perfluorinated Compounds (PFCs). For example, certain OPFRs were degraded by Ultraviolet (UV) radiation, Hydrogen Peroxide (H_2O_2) and Ozone (O_3), while others were resistant to both secondary and tertiary treatment (Cristale et al. 2016).

Concerning PFASs, studies indicated that modern wastewater treatment cannot efficiently remove these compounds for various reasons, such as the presence of PFAS precursors. Mainly two mechanisms have been developed for PFAS remediation: separation-concentration and destruction, but the most promising approach is adsorption, which is the most affordable. However, these mechanisms are not yet ready for full-scale application (Phong Vo et al. 2020) and have not been used in Mediterranean paradigms.

PFCs are considered emerging pollutants within POPs and are used in several household applications but are not biodegradable and tend to accumulate in sludge with conventional wastewater treatment (Ahrens et al. 2011), entering the environment directly or via the degradation of precursor compounds (Prevedouros et al. 2006). Tertiary treatment with membranes, activated carbon, and advanced oxidation processes can be used against these recalcitrant pollutants. Investigation of the distribution and fate of PFCs in Spanish sewage treatment plants has confirmed that removal efficiencies with conventional methods can only partially eliminate these substances (Campo et al. 2014).

Attention to PAHs, as emerging pollutants in the Mediterranean, has been given after new legislation led to the installation of exhaust gas cleaning systems (EGCSs) known as scrubbers, in the engine and boiler systems in commercial ships. After scrubbing, a waste stream (scrubber water) containing high concentrations of potentially toxic organic compounds for aquatic life, such as PAHs and metals, is generated and discharged into the marine environment (Tran 2017). Therefore, considering that the Mediterranean Sea is one of the areas with the heaviest ship traffic, research is trying to decipher potential ecotoxicological effects of scrubbers on various levels of bio communities, from planktonic microbes (Ytreberg et al. 2021) to mussels (Pittura et al. 2018) and fish (Santana et al. 2018). In addition to maritime sources, conventional sources of PAHs, such as agricultural, industrial, and domestic activities, as well as atmospheric transport, have been previously identified. The solutions that can be implemented mainly target conventional sources and include generic waste treatment approaches, similar to those mentioned above. Further research is underway to develop pipelines that involve the biodegradation of PAHs in scrubbers (e.g. see Ismail et al. 2022 for a review).

4.3.6 Source point versus end point solutions

The discussion above focuses on solutions to reduce pollutant inputs along Mediterranean coasts at the source point, targeting basin and urban sources. Such measures are generally easier to implement when they have clear goals, making them less costly, more effective, long-lasting, and easier to monitor. It is often more cost effective to prevent pollution from being created at its source than managing it at the endpoint. However, targeting solutions at the source of pollution is not always straightforward, especially considering dispersed sources, secondary emits, and/or multi-dispersed origins of pollutants. In general, pollution management focuses on altering the human activity that causes the problem, controlling the release of the pollutant and restoring the damaged systems.

Strategies on pollution management at the recipient systems are challenging and have been limited up until now. A first step is the development of quality assessments (e.g. development of appropriate ecological indices) of coastal waters within the scope of the EU MSFD, using integrated approaches combining physical, chemical, and biological elements of the ecosystems. Then, when suppression of the causative pressure at source is insufficient for regime shifts, active restoration by additional management measures based on direct actions should be employed.

For example, for the restoration of seven coastal lagoons in southern France, plans included attempts to restore seagrass meadows by actively planting or seeding and subsequently harvesting their biomass, which stores excessive nutrients. Macroalgal growth can accelerate the decrease of total N and P contents, provided that its biomass is exported from the lagoon (De Wit et al. 2017). Overall, macrophyte and angiosperm transplants in coastal sites are a frequent and effective strategy to reduce external nutrient loading. Over four years of plant transplantations at 32 stations in the Venice Lagoon, extensive meadows were formed over a surface area of approximately 10 km^2 and a rapid recovery of the ecological status of the relevant areas was observed (Sfriso et al. 2021). Similarly, wetland plants promote soil metal adsorption through soil oxygenation. The angiosperm *Paspalum distichum* was found to be a potential phytoremediator of water metal pollution in mesocosm-field experiments in a newly established restored marsh in the Ebro Delta (Spain), highlighting the utility of restored marshes as metal filters in coastal Mediterranean systems. However, this bottom-up approach to nutrient-metal loading management often does not match with community recovery, and restoration is therefore *likely* not apparent (Duarte et al. 2009). Top-down approaches that target the eutrophication results, that is the development of Harmful Algal Blooms (HABs), have thus been examined in theory with the proposal to test filter-feeder species farming being qualified (Petersen et al. 2014). However, these have yet to be applied on large scales in the Mediterranean region due to associated bottlenecks of shellfish farming which impair the beneficial effects on nutrient harvesting (Stadmark and Conley 2011).

Still, long-term solutions involve shifting towards a more circular economy, and a transition towards more sustainable production and consumption. Such a transition may require increased awareness not only at local and national levels, but also at the regional Mediterranean level with all stakeholders involved. It is worth noting that such a transition is a context-dependent, non-linear, evolutionary process that needs to be supported by research.

4.4 Non-indigenous species

4.4.1 Challenges

Warmer conditions, increased salinity, acidity, and in some cases pollutions (Ozer et al. 2022) have encouraged the establishment of non-indigenous species in marine and coastal environments of the Mediterranean (Beca-Carretero et al. 2024). Risks associated with non-indigenous species include potential loss of endemic species whose niches have been overtaken, risks to infrastructure (e.g. power and desalination plants), and sectoral risks, such as food cultivation and loss of recreational values based on existing ecosystems (Katsanevakis et al. 2014). Throughout the Mediterranean, acidification and water warming have caused significant stress for sensitive species and ecosystems and have promoted hardy non-indigenous species (Lacoue-Labarthe et al. 2016), with alien species constituting a significant threat to biodiversity (Giangrande et al. 2020). Several examples exist: in Cyprus, the invasive puffer fish *Lagocephalus sceleratus* (Tetraodontidae) is now outcompeting native fish and their prey, such as the *Octopus vulgaris* (Octopodidae) and squid, which are becoming increasingly scarce (Nader et al. 2012). In the Adriatic Sea, research on the effects of on-going marine sprawl, principally the building of protective infrastructure along coastlines to prevent their change from erosion and accretion processes as well as for anthropogenic needs, has favoured habitats for invasive species and caused the loss of native local biodiversity (Airoldi and Bulleri 2011). Other non-indigenous species, such as jellyfish *(Rhopilema nomadica)* have benefited from climate change effects and negatively impacted both tourism and infrastructure. It is known that non-indigenous species have a better hold in areas where ecosystems are already stressed. This is often the situation near desalination plants where there is some evidence that *Posidonia meadows* are affected by brine outfall and fishing practices, such as trawling, where Lessepsian migrations have taken hold (Kiparissis et al. 2011; Xevgenos et al. 2021).

4.4.2 Solutions

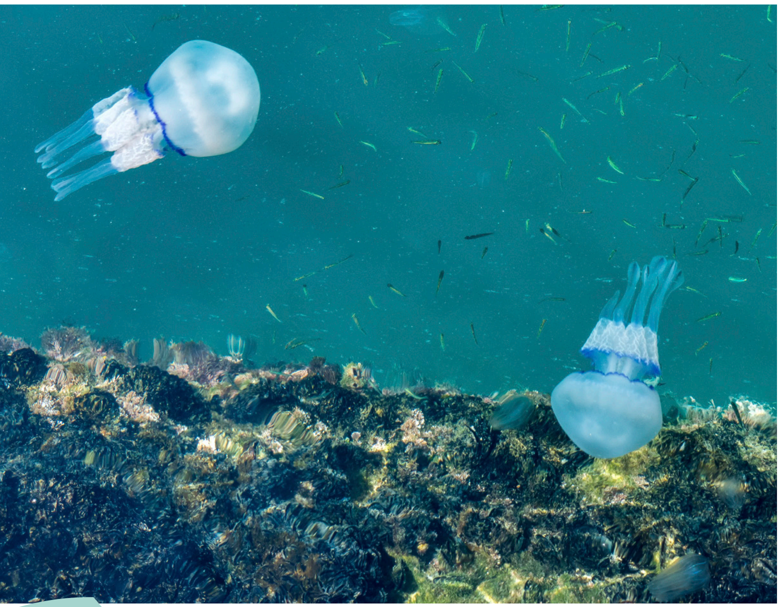
While such problems are observed throughout the Mediterranean region, few solutions have advanced and only in a few locations. In general, controlling non-indigenous species in marine environments faces considerable challenges compared to terrestrial environments (Giakoumi et al. 2019). Some of the most common approaches for reducing non-indigenous species include eradication initiatives, commercial efforts to develop new ways to use the abundance of some of these organisms, and tailoring planning and development to encourage and protect native species by providing suitable habitat conditions.

Although successful examples of eradication exist globally, this approach is challenging, and early detection seems to be key in determining its success (Giakoumi et al. 2019; Leza et al. 2021). To this end, citizen-science initiatives (Giovos et al. 2019; Kousteni et al. 2022) can be employed to eradicate invasive species.

Beyond eradication, improved planning and construction of marine infrastructure and even marine 'urbanisation' can be developed in order to provide habitat and ecosystem services (Dafforn et al. 2015). Many of the 1000 non-indigenous species recorded so far have been found in the eastern Mediterranean and are detrimental to fisheries, but some are now targeted commercially (Lacoue-Labarthe et al. 2016). Tailoring development and planning to encourage native species includes the establishment of protected areas that would allow ecological connectivity (to counter habitat fragmentation) for endemic and local species. A total of 39 Specially Protected Areas of Mediterranean Importance (SPAMIs) is listed under the Barcelona Convention. Much more attention is needed to move forward with the official recognition of these SPAMIs. This attention needs to include many different kinds of actions, from providing some kind of regulatory protection of these areas to even simply raising awareness of their existence and importance. There is strong evidence *(high confidence)* that most of the protected areas in the Mediterranean Sea are under strain from variable climate change and that this is detrimental to native biota (Kyprioti et al. 2021).

Nevertheless, significant gaps in knowledge still exist regarding non-indigenous species, with studies suggesting that assessments of the potential benefits of various species are still required before management actions can take place (Green et al. 2014; Katsanevakis et al., 2014; Giangrande et al., 2020). Although various approaches, such as those described earlier, do exist, management and control of non-indigenous species remains challenging. In a study examining management priorities among experts for the management and control of marine invasive species, Giakoumi et al. (2019) concluded that raising public awareness and encouraging the commercial use of invasive species were highly prioritised, whereas biological control actions were considered the least applicable.

A critical look at extractive practices is also lacking, especially in academic circles, professional training programs and government (public sector) ministries and authorities. Emphasis on economic incentives to reduce the use of non-indigenous species, for example in public spaces, could be adopted by states and regions who then offer economic incentives to local municipalities and even non-governmental organisations (NGOs).



4.5 Risk synergies and management considerations

A further challenge for managing coastal risks, which is generally overlooked when preparing for coping with climate and environmental risks, is the interaction of different processes at different temporal or spatial scales (Zscheischler et al. 2018). These interactions can result from drivers that occur simultaneously or in succession and whose direct impacts overlap, spatially and temporally and include a broad range of multi-hazard types, such as compound and cascading events (de Ruiter et al. 2020).

The Mediterranean appears to have a high potential for the development of different types of consecutive events. Examples include the north-western coast, which is experiencing the highest compound flooding probability in Europe (Bevacqua et al. 2019); the Iberian Peninsula, northern Italy, northern Africa, and the Balkans, which have been identified as the main hotspots where the occurrence of drought events in the spring or early summer could lead to extremely hot temperatures in the summer (Russo et al. 2019); the significant increase in the number of compound warm spells and droughts in the entire Mediterranean Basin over the last 40 years, particularly in late spring, with the increase being attributed to temperature rise rather than lack of rainfall (Vogel et al. 2021); and the co-occurrence of daily rainfall extremes along the crest line of the Massif Central in the French Mediterranean region (Blanchet and Creutin 2017).

Future projections indicate that the probability of these types of events may increase. Ruffault et al. (2018) found that increasing drought conditions projected by climate change scenarios could affect the dryness of fuel compartments and lead to a higher frequency of extreme wildfire events. Wildfires may in turn lead to elevated organic carbon, iron, and particles, which are eventually discharged into the ocean, affecting coastal chemistry and even leading to a decline in coastal habitats and their functions (Herbert-Read et al. 2022).

4.5.1 Managing the risks of consecutive events

Consecutive events are not considered in the planning of responses to risks, which can lead to serious issues: first, the sequential occurrence of each event and the amount of time between two disasters can substantially affect the vulnerability to the next hazard (de Ruiter et al. 2020); second, solutions aimed at reducing the impacts of single drivers (e.g. coastal flooding) may exacerbate the effects of the compounding driver (e.g. pluvial flooding), thus rendering any prevention measures inadequate for their purpose and leading to maladaptation.

Limited scientific understanding of consecutive events and in particular their spatial and temporal dynamics, is one of the main barriers to managing the risks of these events. Further multi-hazard assessments that account not only for consecutive risks, but also for the planning of specific measures are essential as wrong decisions for adapting to consecutive events can considerably exacerbate risks to infrastructure and human life. Lastly, as these hazards are dynamic in nature (de Ruiter et al. 2020) and can cross national boundaries, establishing international cooperation between Mediterranean states in disaster response is essential for managing risks.

Tsunamis

Given the tsunami threat in the Mediterranean region *(Chapter 3)*, the Intergovernmental Coordination Group for the Tsunami Early Warning and Mitigation System in the North-Eastern Atlantic, the Mediterranean and Connected Seas (ICG/NEAMTWS)[50] was formed in response to the tragic tsunami in the Indian Ocean on 26 December 2004. The Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) received a mandate from the international community in June 2005 to coordinate and develop a Tsunami Early Warning System for the region. This system is known as the NEAMTWS, for North-Eastern Atlantic, Mediterranean, and Connected Seas Tsunami Warning Systems. The guidelines for the

50 https://tsunami.ioc.unesco.org/en/neam/icg-neamtws?hub=50

NEAMTWS activities are compiled in the NEAMTWS Implementation Plan (IOC 2007).

At present, five institutions in the tsunami community act as accredited Tsunami Service Providers (TSP) as part of the regional system in the NEAMTWS, namely NOA, Greece[51], the INGV (Italy)[52], CENALT (France)[53], KOERI (Türkiye)[54], and IPMA (Portugal)[55]. Furthermore, additional institutions participate in National Tsunami Warning Systems (NTWS) (e.g. in Romania and Spain). The TSPs and NTWSs are also involved in national contingency planning for tsunamis, with hazard and risk mapping. This necessitates a strong link and continuous interaction with civil protection agencies and local authorities responsible for the implementation of local emergency plans. Such interactions have included hazard mapping and evacuation planning.

There is currently a growing consideration of tsunami risk in the region, in which UNESCO plays a major role in encouraging and supporting the preparedness of exposed coastal communities through different means. These include promoting the maintenance of the JRC-IDSL (Joint Research Center - Inexpensive Device for Sea Level devices) tide-gauges and encouraging the implementation of the Tsunami Ready international recognition programme for municipalities in the NEAM region. The Tsunami Ready Recognition Programme is an international community-based recognition programme developed by the IOC–UNESCO. It aims to build resilient communities through awareness and preparedness strategies designed to protect lives, livelihoods, and property from tsunamis in different regions.

4.5.2 Residual risks

Despite any adaptation or mitigation measures that will be undertaken, residual risks of loss and damage are inevitable. Residual risk, defined as 'the risk that remains in unmanaged form, even when effective disaster risk reduction measures are in place, and for which emergency response and recovery capacities must be maintained' (UNDRR 2017) is an essential component of coastal risk management. However, identifying the response limits of societies and ecosystems is challenging as these limits dynamically evolve in physical and socioeconomic systems with time. For example, Reimann et al. (2018) identified increasing residual flood risks for the Mediterranean coasts under SSP5-8.5 due to the high concentration of population and assets in the coastal zone.

Residual risks are usually not quantified or even identified for the Mediterranean coastal regions, largely due to limited knowledge on the actual response needs to the different hazards. However, a few exceptions do exist where reference to residual risk is made in national legislation (e.g. see Fiori et al. 2023). Understanding residual risk will form a key element of future adaptation policies, particularly in a rapidly developing coastal environment where future risk will concentrate on areas that are currently experiencing low or no risk. As Mediterranean nations are increasingly in a position to shape their future coastline, managing residual risk needs to be a primary consideration in this process.

51 National Observatory of Athens: https://www.noa.gr/en/

52 Istituto Nazionale di Geofisica e Vulanologia: https://www.ingv.it/

53 Centre d'Alerte aux Tsunamis: https://www.info-tsunami.fr/

54 Kandilli Observatory and Earthquake Research Institute: http://www.koeri.boun.edu.tr/new/en

55 Instituto Português do Mar e da Atmosfera: https://www.ipma.pt/pt/otempo/prev.localidade.hora/

4.6 Barriers to effective responses

Responses to coastal risks are often hampered by different factors. Such factors include technical, economic and management barriers (Sánchez-Arcilla et al. 2022), governance barriers, stakeholder perceptions (Clément et al. 2015) or barriers related to financing coastal adaptation or to social conflicts induced by adaptation processes (Hinkel et al. 2018).

Due to the geographically diverse socio-economic settings and the lack of a tradition of coastal adaptation along large parts of the basin, adaptation to coastal risks in the Mediterranean faces different types of barriers. For example, Hinkel et al. (2018) find that the Catalan coastal zone does not currently face major technological, financial, or economic barriers and that social conflict can be the main impediment in coastal adaptation. Work on the perceptions of responses related to issues such as retreat, erosion and loss of ecosystem services due to sea level rise in the Mediterranean coastal zone (e.g. in France, Clément et al. 2015, and in Greece, Tourlioti et al. 2021) indicates differences in perceptions regarding financing of coastal adaptation and compensation of damage. At the same time Schleyer-Lindenmann et al. (2022) identify an optimism bias in a case study for the cities of Marseille and Nice (France), whereby people are aware of climate change but appear not to worry about it. Such perceptions may be related to the lack of specialised and tailored information on risks related, for example to sea level rise and specifically the lack of coastal climate services (Le Cozannet et al. 2017; Valente and Veloso-Gomes 2020), or to the lack of risk assessments for major population or commercial centres, as for example, in port cities (Valente and Veloso-Gomes 2020). Such information would facilitate the incorporation of adaptation considerations into planning and would potentially mobilise public support regarding the need for adaptation to coastal risks. Lastly, prioritising the implementation of the existing legislation, namely the ICZM protocol, which is currently impeded by these and other factors, would be a substantial step towards overcoming barriers and promoting effective responses.

4.7 Science-policy interface

4.7.1 Defining science needed for policymaking in times of climate emergency

The science-policy interface requires integrating the knowledge produced by academia and research institutions and local, indigenous, and traditional knowledge (UNEP 2021). Also, interdisciplinary approaches are crucial for the science-policy interface, where social sciences and humanities need to be better brought into play (Visser 2004; Christie 2011; Šucha and Dewar 2020). This is particularly important in the context of the Mediterranean coastal areas, where problems and consequences of climate change are numerous and interconnected (UNEP/MAP and Plan Bleu 2019).

Strengthening governance for climate action is a task that goes beyond established management structures, as its successful implementation requires a broad social partnership. The governance setting would enable co-creation– interlinked collaborative approaches aimed at increasing dialogue, trust, understanding of needs, and diversity of input, which can increase the importance and impact of evidence for public policies (Sienkiewicz and Mair 2020). Given the complexity of the challenges caused by climate change, science can play a crucial role in strengthening governance settings (PAP/RAC 2021).

4.7.2 Two worlds – science and policymaking: barriers, obstacles, needs, opportunities

Science and policy may be among the most different domains in terms of goals, values, timespan, theme span, and accountability considering those falling into the category of public sector jobs (Choi et al. 2005). The goal for policymakers is to achieve their vision by gaining and keeping the public's support and making timely decisions. The goal of scientists is to advance science by revealing scientific truth, and, in order to explore and understand the world, the research issue must be defined as precisely as possible. While the policymaker may think about 'everything' and therefore consider the themes from a general perspective, scientists go very deep into the topic of their research. While a policymaker's time horizon depends on the approval of the community (voters), therefore mostly count on one political cycle at a time, the time horizon of the scientist most often is focused on one human lifetime. This is probably the biggest difference between the two fields. Due to the time and theme span, policymakers do not dedicate substantial amounts of time to any particular issue. These two spans are also the reason these two groups hold different values and speak different languages (Abdrabo and Hassaan 2020).

While scientists are accountable to their peers and editors, policymakers are accountable to governments, political parties, taxpayers, and citizens. These differences may hinder the creation of trustworthy relationships, which are key in sensitive and dynamic policy environments such as the ICZM arena.

A framework for permanent collaboration and co-creation can enable the inclusion of all sciences and all types of knowledge and secure transparent, relevant, and efficient science communication (Ivčević et al. 2021). The fruitful collaboration between scientists and policymakers can be achieved with major adaptations from both sides through mutual adjusting of norms and expectations, through dialogue, relationships, and mutual learning (Sienkiewicz and Mair 2020). Such collaboration would need new approaches to communicate climate science to increase understanding, and mutual respect, and trust while improving climate literacy so that policymakers become accountable to climate-literate voters (Howarth et al. 2020).

4.7.3 Possible solutions to bring science closer to policymakers and to enable policymakers to use science

Science plays a crucial role in providing evidence that supports the policymaking process. Engaging scientists in all stages of policymaking could therefore bridge science and policy closer together (Sienkiewicz and Mair 2020). Multi-directional rather than one-way linear relationships between science and policy may allow for exchanges, co-evolution, and joint development of knowledge to enrich both decision-making and supportive research approaches (Young et al. 2013).

For example, UNEP/MAP and the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean ('Barcelona Convention')[56], adopted in 1976 and amended in 1995, including its seven additional protocols, provide a framework for institutional cooperation among all Mediterranean countries and the EU. Also, the Contracting Parties of the Barcelona Convention adopted several decisions calling for a stronger science-policy interface, including, for example, those on the Mediterranean Strategy for Sustainable Development (MSSD) 2016–2015 calling for a participatory approach to policy and decision-making (UNEP/MAP 2016b; Gual Soler and Perez-Porro 2021). Additionally, during the biannual UNEP/MAP Work Programme (2016-1017), the Parties called for efforts to structure relationships between the UNEP/MAP system and scientific communities by creating scientific committees and expert groups with an advisory role to support policymaking processes (UNEP/MAP 2016a, Strategic Outcome 1.4.4, p.717; UNEP/MAP and Plan Bleu 2019).

The network of Mediterranean Experts on Climate and environmental Change (MedECC) was created in 2015 as open, independent network of international scientific experts. It is acting as a mechanism of ongoing support for decision-makers and the general public based on available scientific information and ongoing research. The creation of MedECC was driven by the needs and intentions of several regional institutions, including the UNEP/MAP, through the MSSD 2016-2025 and the Regional Framework for Climate Change Adaptation in the Mediterranean (UNEP/MAP 2017), and the Expert Group on Climate Change of the Union for the Mediterranean (UfM CCEG[57]) (UNEP/MAP and Plan Bleu 2019).

Furthermore, in 2012, the UfM Regional Platform in Research and Innovation[58] adopted a new agenda for cooperation in research and innovation in the region, with a focus on renewable energy, health, and climate change. Meanwhile, the Mediterranean Universities Union[59], founded in 1991, is an association of universities from the Mediterranean countries and aims to develop research and education in the Euro-Mediterranean area UfM (UNEP/MAP and Plan Bleu 2019).

Three criteria recommended for scientific evidence in support of specific policies are (Parkhurst 2016):

- Addressing the policy concern at hand, instead of any loosely related topic.
- Being constructed in ways useful to address policy concerns, methodologically able to answer the questions at hand.
- Being applied to the policy context.

At the institutional level, strengthening governance for climate action can be achieved through the creation of scientific consultancy bodies aiming to identify and prioritise climate action while securing vertical and horizontal integration and transfer of knowledge and experiences. Such bodies can constitute a platform for cooperation between science and policymakers and represent anchors that will help climate action to have continuity after political changes in the governing structures (PAP/RAC 2021). The creation of such bodies, including advisory councils and boards are examples of innovating governance models. Additionally, having local and regional scientific networks with local and regional policymakers could enable their timely involvement in relevant policymaking.

Such institutional arrangements can assist in both answering the policy concerns at hand and keeping a transparent long-term perspective (Haasnoot et al. 2013). Lastly, citizen science organisations are emerging as key partners for building resilience along the coastlines. From data collection and monitoring to action, advocacy, and education, citizen science organisations may play a pivotal role in reducing coastal risks for society.

56 https://www.unep.org/unepmap/who-we-are/barcelona-convention-and-protocols

57 https://ufmsecretariat.org/ufm-climate-change-expert-group/

58 https://ufmsecretariat.org/platform/ufm-regional-platform-on-research-and-innovation/

59 https://www.uni-med.net/about-us/

Box 4.1

Examples of science policy collaboration in the Mediterranean

As introduced in *Chapter 1*, several science-policy collaboration initiatives have been launched across the Mediterranean at the regional, sub-regional, and national levels.

At the regional level, the science-policy interface has been supported through networks of national governments including for instance the Mediterranean Action Plan (MAP) . The first Regional Sea Programmes of the UNEP launched in 1975 has at present its seven Protocols that provide a framework for collaboration for its 22 Contracting parties – Mediterranean countries and the EU. Today, the MAP[60] structure consists of seven Regional Action Centres, each one addressing a specific topic. Within this framework, many projects have been implemented within which collaboration between scientists, experts, and decision-makers, as well as civil society and the private sector, has been achieved.

Since 2016, Mediterranean countries have adopted the Mediterranean Strategy for Sustainable Development, a strategic guiding document for all stakeholders and partners to translate the 2030 Agenda for Sustainable Development at the regional, sub-regional, and national levels (UNEP/MAP 2016b). The same year, the Mediterranean countries approved the Regional Climate Change Adaptation framework for the Mediterranean Marine and Coastal Areas (UNEP/MAP 2017).

In 2008, the UfM was created. It is an intergovernmental institution bringing together all 27 EU countries and the 15 countries of the southern and eastern Mediterranean. In 2014, UfM established its Climate Change Expert Group [61]to advance the discussion on climate change priority actions and accelerate the identification and development of concrete projects and initiatives.

Finally, in 2015 the MedECC was launched, and today it operates as an open and independent network of more than 400 scientists working towards a regional science-policy interface for climate and other environmental changes across the Mediterranean. MedECC is supported by Plan Bleu/CAR (UNEP/MAP) and UfM through the funding of the Swedish International Development Cooperation Agency (SIDA).

Additionally, scientific networks at the national and sub-national levels have been founded to support policymaking. For example, in Italy there is a scientific network called the National Research Group for Coastal Environment Issues (GNRAC)[62], founded in 2006 to promote and disseminate studies on the status, conservation, and management of Italian coasts. With more than 250 members, researchers, local administrators, and professionals, GNRAC has become a recognised expert hub for coastal issues in Italy, but the connection with policymakers is only marginal and occasional.

Moreover, as highlighted by PAP/RAC (PAP/RAC 2019), governance, at its core, is made up of various boards and councils because they provide the easiest to link governance with management. Examples of Advisory bodies are presented below. For instance, the Academic Advisory Board for the Barcelona 2030 Agenda[63] is an advisory body made up of Barcelona's academic community to advise the City Council's governing team on the development of the 2030 Agenda and the achievement of the SDGs in the city, promote the undertaking of studies with different stakeholders and propose actions/projects.

Similarly, the advisory board for integrated planning and management of coastal and marine areas of the Split–Dalmatia County in Croatia is part of the governance mechanism established with the Coastal Plan for Split–Dalmatia County. The advisory board consists of the University, Institutes, and NGO representatives. In addition to the Advisory Board, the governance mechanism consists of a Coordination Board (representatives of institutions managing the coastal zone and the sea) and a Partnership Board (cities and municipalities).

Based on the everything presented above, having an Advisory Board with top-level policymakers from all sectors, from all sciences, and at supra-local/metropolitan levels, nested in the bridging organisation could ensure proper positioning of the science-policy interface.

New networks of science-policy interfaces as the centres of governance networks could be a way towards more science in policymaking. Expanding science communication to communities would be a step towards tomorrow's climate literate and aware citizens. The science-policy-community interface is the key to success for the systemic transformation of our society.

60 https://www.unep.org/unepmap/

61 https://ufmsecretariat.org/ufm-climate-change-expert-group/

62 https://www.gnrac.it/en

63 https://ajuntament.barcelona.cat/agenda2030/en/who-we-are/academic-advisory-board-barcelona-2030-agenda

4.8 Final remarks

Addressing the adaptation challenges raised in the previous sections will require an integrated and systemic approach consistently applied across scales, from municipalities to governments (IPCC 2022b). This can build upon existing integrated coastal management approaches, with more attention to system transitions compliant with sustainable development goals and climate and biodiversity targets. Many projects have found that the biggest challenges lie in achieving good governance for climate. There is a pressing need for increased application of social sciences and humanities to understand the mechanisms through which citizens react, oppose, and adapt to the increasing coastal risks. In addition, social sciences and humanities could provide precious support for creating a favourable environment for enhancing resilience, implementing agreed goals, plans and strategies. It is worth noting that knowledge availability and accessibility at different sub-regions of the Mediterranean could lead to a better understanding of the coastal risks facing the region and enable better cooperation and potential for management of such risks.

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