Deliverable 3.2 new actions fostering MSP contribution to Green Deal

Supplementary report

An integrated approach to improve climate proofing of Maritime Spatial Planning in the Italian Northern Adriatic Sea

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Authors	Emiliano Ramieri (CNR ISMAR), Chiara Castellani (Thetis), Elisa Andreoli (Thetis), Andrea Barbanti (CNR ISMAR), Davide Bonaldo (CNR ISMAR), Ginevra Capurso (CNR ISMAR), Elena Gissi (CNR ISMAR), Stefano Menegon (CNR ISMAR)

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List of Abbreviations

ARPA	Regional agency for environmental protection (Italy)
AZA	Allocated Zones for Aquaculture
EBSA	Ecologically or Biologically Significant Marine Areas
FAO	Food and Agriculture Organisation
ICZM	Integrated Coastal Zone Management
IMO	International Maritime Organisation
IMMA	Important Marine Mammal Areas
ISRA	Important Shark Ray areas
IPCC	Intergovernmental Panel for Climate Change
KTMs	Key Type Measures
MPAs	Marine Protected Areas
MRF	Marine Recreational Fisheries
MSFD	Marine Strategy Framework Directive
MSP	Maritime Spatial Planning
NadDw	North Adriatic Deep Water
NBS	Nature Based Solution
OECMs	Other Effective Area-based Conservation Measures
PITESAI	Plan for the Sustainable Energy Transition of the Eligible Areas (Italy)
RCP	Representative Concentration Pathways
SSP	Shared Socio-economic Pathways
WFD	Water Framework Directive
ZSC	Special conservation zones

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1. Introduction

The EU Maritime Spatial Planning (MSP) Directive (2014/89/EU) requires Member States to prepare maritime spatial plans to achieve a balanced and sustainable use of marine space. It recognises climate change as a threat and highlights the need to increase resilience both on land and at sea. While solving conflicts among different economic sectors, MSP should pursue the "preservation, protection and improvement of the environment, including resilience to climate change impacts". Adaptive marine plans or "climate-proof" plans address this issue, as widely recognised in the literature (Frazão Santos et al., 2021; Gissi et al., 2019; Maragno et al., 2020; Queirós et al., 2021).

The EU MSP Directive also recognises, among several maritime uses, the high and rapidly increasing demand for installations for the production of energy from renewable sources and requires the alignment between the timelines for maritime spatial plans and the timelines set out in other relevant legislation, including the Directive 2009/28/EC, about the share of energy from renewable sources. Indeed, while responding to the growing challenges of climate change in maritime sectors, MSP also supports countries in meeting their national and international climate targets by harnessing the economic opportunities of the decarbonization pathway (PROBLUE, 2021).

1.1 Climate change affects MSP sectors and activities

The conceptual model developed by (Frazão Santos et al., 2020) delineates that climate-induced changes in marine conditions (meteo-marine regimes, thermohaline properties and circulation, frequency and intensity of extreme events and chemical-physical variables) and in marine ecosystems will lead to changes in the distribution of human uses and activities at sea. Such redistribution of uses will lead to potential use–use and use–environment conflicts, in addition to existing ones.

In particular, as illustrated in the scheme of Figure 1 based on the above-mentioned conceptual model, climate-induced threats to marine ecosystems might both determine the alteration of ecosystem services and advance the need for enhanced environmental protection to preserve the most vulnerable habitats and species. In this regard, special protection might be advocated to safeguard climate *refugia* and to ensure networks of protected areas that can allow climate-induced migration of mobile species. Moreover, climate change (mainly sea level rise and spatial and temporal change in storminess patterns) will lead to increasing impacts on coastal areas (erosion, flooding, salt intrusion on coastal water bodies), calling for increasingly strong (and possibly not always sustainable) defence interventions and new coastal management strategies. In their turn, especially whenever these strategies are not implemented through an ecosystem approach, conflicts with environmental protection or other uses might increase, both on the coastal strip (e.g. landscape alteration) and offshore (extraction of marine sand deposits for beach nourishment). Various examples of how climate change may cause the redistribution of uses, potentially enabling new conflicts, are available in the literature. Some of the most reported issues refer to fisheries, aquaculture, coastal defence and tourism.

Concerning fisheries, a commonly reported issue is that fishing grounds are expected to change in response to variations in temperature patterns and other induced chemical-physical parameters (salinity, pH, oxygen). Indeed, warm-adapted fish are expanding across the Mediterranean basin (Azzurro et al., 2019) with an expected decreasing habitat suitability for many local species and an increase of tropical species in several basins, including the Adriatic Sea (Cavraro et al., 2022). Changes in fish stock productivity and distribution may cause stress on fisheries, even with an international dimension, creating the conditions for conflicts and posing new challenges for the existing fisheries management institutions (Mendenhall et al., 2020).

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Similar issues refer to aquaculture. The expansion of marine aquaculture commonly raises several issues, such as how to site such facilities, what kinds of marine aquaculture to prioritize, and/or how to control or minimize aquaculture's environmental impacts (Craig, 2019). Increasing global temperatures (and related physical and chemical conditions) and increasing frequency of heatwaves in the Mediterranean Sea (Semia Cherif et al., 2020) further influence the process of designing new areas for aquaculture. Especially for coastal waters, further issues can be related to changes in water quality and trophic conditions, induced by both changes in oceanographic conditions as well as of land-based processes (e.g. variations in river discharges to the sea or sewage overflows due to intensification of storms). Indeed, spatial planning of farms accounting for climate-related risks is considered an adaptation solution to climate change for the aquaculture sector (FAO, 2018).

Concerning coastal defence, it is well recognised that climate change is expected to affect coastal areas due to the combined effect of sea level rise and modifications in storms and storm surge regimes. This can cause coastal erosion and increase the risk of temporary or permanent submersion in low-lying areas. In turn, hard engineering interventions made to safeguard the coastline may cause coastal squeezing with loss of saltmarshes, wetlands and other important habitats. Sand nourishment is the most popular shore reconstruction strategy to counteract the erosion of coastal areas (Targusi et al., 2019). Along the Adriatic coast, it is commonly used to preserve coastal tourism, which largely relies on wide sandy beaches. In Italy, the use of marine sand deposits (relict sands) dates back to the beginning of the 1990s (Targusi et al., 2019). With an increasing request for sand to counteract an increasing erosion trend of coastal areas due to climate change, the pressure on offshore sand deposits is expected to increase as well as the conflicts with other maritime uses, especially fisheries. At the same time, human-induced changes in the natural sediment transport (from river basins to the sea) are further impacting on the fragile sediment budget of coastal systems. Relict sands, increasingly used for compensating such sand losses, are a non-renewable resource of material that needs to be carefully managed according to the principles of the ecosystem approach.

Climate change, on top of several human activities, affects both the supply and demand of tourism offers and services (Arabadzhyan et al., 2021). Especially in southern European countries, summer heatwaves create unfavourable conditions for tourism, with possible changes in preferred destinations, The availability of beaches for recreation is at risk from erosion and the quality of marine ecosystems may lose its attractiveness (Santos-Lacueva et al., 2017) due to their degradation. According to a JRC study (European Commission Joint Research Centre, 2023) that simulated the impacts of climate change on future tourism demand in Europe, coastal regions are the most impacted area. A clear north-south pattern emerged, with Northern regions mainly benefitting from climate change and southern regions facing significant reductions in tourism demand. The seasonal distribution of tourism is also expected to change. It follows that the Mediterranean basin, one of the most popular destinations of tourist fluxes, is expected to be particularly exposed to climate change impacts.

In addition, the effects of climate change can be also investigated for assessing the siting of new potential facilities for renewable energy production (e.g. long-term wind changes) and open new opportunities for maritime transport, especially in northern areas (unexplored shifting northward routes). These two issues, despite their global relevance, are not primarily relevant for this report that is specifically focussed on the Adriatic basin.

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1.2. MSP is part of the solutions for adaptation and mitigation of climate change

The cascading effects of climate change described above can cause a redistribution of maritime uses and new potential conflicts, all core elements of any MSP process and plan. It follows that climate change is affecting MSP by posing new challenges, but also that a climate-proof MSP can be part of the solutions available to reduce the impacts of climate change, mainstreaming the adaptation process in sea planning and management, in agreement with the goals of the European Green Deal.

Although the focus of this document is on adaptation to climate change within the MSP process, opportunities for mitigation are manifold. Decarbonisation can be pursued through the allocation of space for specific uses (such as offshore renewable energy, low-carbon fuel bunkering, optimised transport routes and low-carbon fuels (PROBLUE, 2021; Quero García et al., 2021) and the preservation of blue carbon ecosystems (Bax et al., 2022) with high potential for carbon sequestration and storage. Although they are not properly spatial measures, specific measures pursuing the reduction of greenhouse gasses for specific sectors (e.g. fisheries and aquaculture) can be also directly incorporated into MSP.

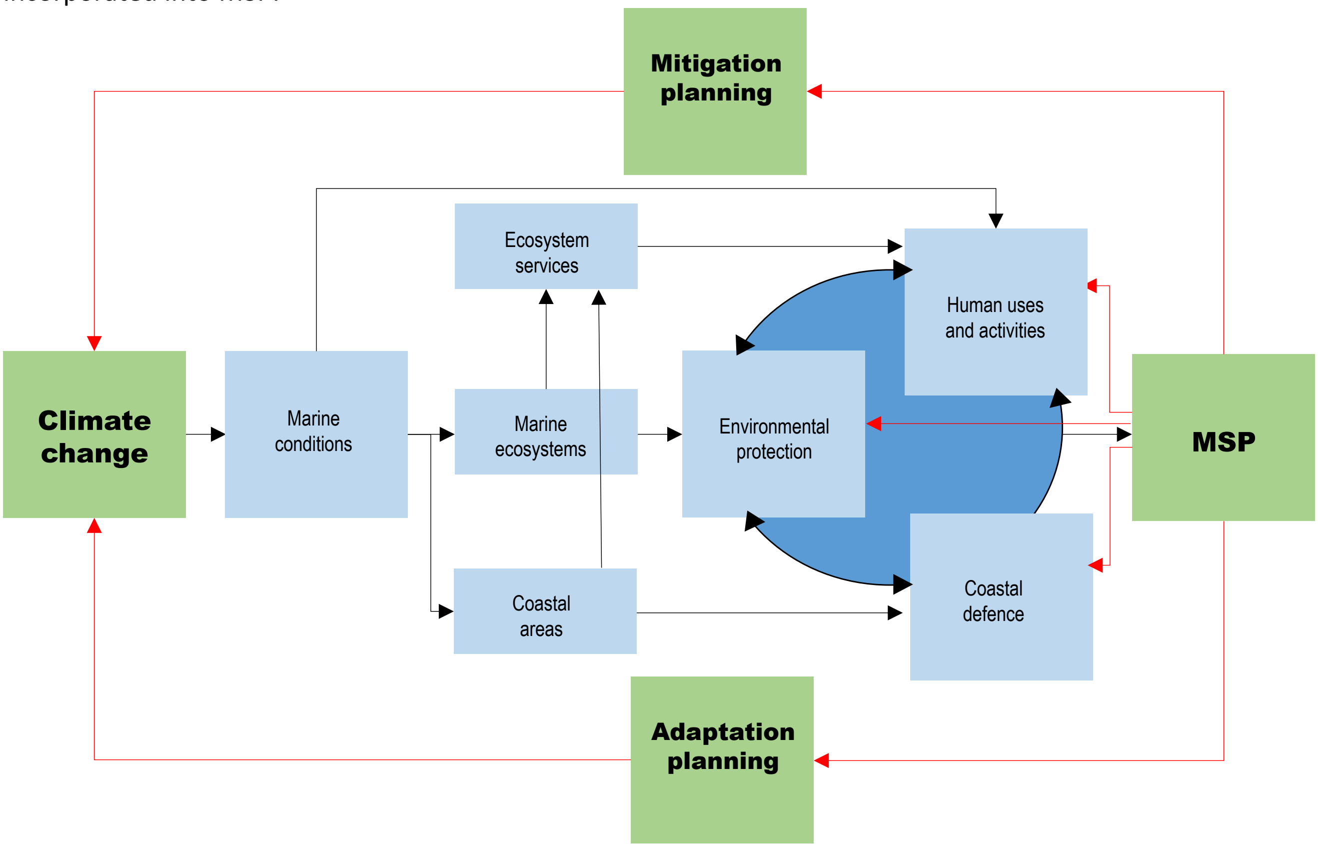

Figure 1. Relationships between climate change and MSP. Own elaboration based on the previously designed conceptual model of (Frazão Santos et al., 2020). Climate change is modifying sea conditions with a series of cascading effects on core elements of MSP (black arrows). At the same time, a climate-proof and climate-smart MSP are effective adaptation and mitigation tools that contribute to counteract these effects (red arrows) and decelerate climate change.

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1.3 MSP can incorporate climate change throughout the entire process

A climate-proof MSP incorporates climate information throughout the entire planning process. The ideal outcome is a climate-informed and flexible plan, easily adaptable to changing conditions and the evolving of scientific knowledge. Key elements that a climate-proof plan needs to address can be traced back to the following elements:

- Understanding what are the main impacts of climate change and the most vulnerable maritime sectors and activities related to environmental protection and landscape preservation;
- Aligning the MSP vision and objectives with long-term objectives of climate change mitigation and adaptation strategies and policies;
- Identifying the most vulnerable coastal and marine areas in present and future conditions;
- Identifying adaptation actions that can be promoted by the maritime spatial plan;
- Identifying and strengthening synergies with mitigation and other policy objectives (e.g. environmental protection, sustainable blue economy development, food production);
- Monitoring of climatic changes and related effects as well as periodic evaluation of adaptation measures;
- Involving stakeholders in the entire MSP process on specific aspects related to climate change, considering their different experiences, perceptions and expectations.

1.4 Incorporating climate change in MSP is challenging

MSP development and implementation must deal with several conceptual and overarching challenges, such as the proper incorporation of the ecosystem approach, the full recognition of land-sea interactions and the embracement of fair and just transition aspects. Climate change presents additional, cross-cutting challenges to MSP. First, dealing with climate change implies working with uncertainties. Five main different climate scenarios are available from the global scientific community (Sixth Assessment IPCC), each of them incorporating a likely interval of different values for climate variables. Vulnerability studies usually compare different scenarios to understand the range of the expected impacts, thus multiplying different possible combinations of results.

Second, there is still limited knowledge of the processes underlying several of the climate change impacts (Rilov et al., 2019), the quantification of such impacts on the maritime sectors and the adaptation solutions available. In particular, the success and limiting factors of various adaptation options in the marine environment should be better investigated through practical examples that are still scarce (Miller et al., 2018) as well as their outcomes should be monitored and tracked over time to prove their effectiveness and sustainability in the long-term. Third, the rapidly changing knowledge on climate change requires increasingly flexible and adaptive planning approaches, according to the learning-by-doing approach and coherent and clear guidance about how to address the topic is still lacking. On top of all these challenges, bridging MSP with climate change adaptation planning implies dealing with different horizon times, combining short-term goals of sector policies with longer-term projections of climate change.

It follows that a few maritime spatial plans integrate climate change considerations in their general planning framework (Frazão Santos et al., 2020; Gissi et al., 2019), towards a proper climate-proof approach. Some plans provide examples of MSP-driven adaptation related to specific sectors, uses or components of the MSP process (Cervera-Núñez et al., 2023).

1.5 Scope and context of this report

The MSP-GREEN project runs from 2022 to 2024 and contributes to aligning maritime spatial plans to the ambition of the EGD by creating a framework for plans as enablers of the marine components of the EGD. The framework aims to provide a cross-cutting approach to the EGD key topics relevant to the marine environment and sustainable transition of the blue economy: climate change, circular blue economy, marine biodiversity, marine renewable energies, and sustainable food provision. The specific objectives of the project are to:

- Assess whether and how MSP plans have considered the EGD objectives;
- Assess what are the major gaps, challenges, and trade-offs in mainstreaming EGD into MSP;
- Identify and exchange valuable practices of incorporation of EGD elements in MSP plans;
- Identify, design, and start implementing additional actions to strengthen the implementation of EGD-related objectives;
- Provide recommendations to EU countries on how to use MSP in fostering the achievement of the EGD goals
- Engage regional sea communities in a dialogue on the EGD ambition and the role of marine planning for a sustainable blue economy.

This document is a supplementary report of Deliverable 3.2 (D3.2) of the MSP GREEN project (Arki et al., 2024). D3.2 presents and discusses a set of examples of new actions developed by the project partners to strengthen the role of MSP in fostering the achievement of selected EGD objectives in their countries.

This supplementary report provides a detailed description of the new action "An integrated approach towards the climate proofing of maritime spatial planning in the Italian Northern Adriatic Sea", briefly presented in D3.2. The marine area addressed by this action includes the territorial marine waters (within 12 nautical miles) facing four different Italian regions (Friuli Venezia Giulia, Veneto, Emilia Romagna and Marche) and the offshore area that extends over the continental platform, until the agreed median line that marks the boundary with Croatian and Slovenian waters. The design of the new action is based on a preliminary analysis of climate change impacts in the Northern Adriatic Sea and of the consequential risks for the marine environment and the most representative maritime sectors of the area.

Besides this introduction, Chapter 2 presents an overview of the Northern Adriatic Sea, and introduces the main geographical features of the basin and the main sectors of the blue economy. Chapter 3 introduces the Italian MSP plan for the Adriatic and describes to what extent climate change is covered. The main climate change impacts expected for the marine area of the Northern Adriatic Sea are described in Chapter 4, based on the main insights from the literature. The new action is finally designed in Chapter 5, following the typical steps of the adaptation policy cycle. The need for establishing a multi-level and cross-sector governance mechanism is remarked, as well as the early involvement of stakeholders and experts in the field of climate change. Preliminary impact chains are proposed for key sectors of the Northern Adriatic Sea, showcasing the cascading effects of climate change and the main vulnerability and exposure elements. A list of possible adaptation options that might be relevant to the MSP plan of the Northern Adriatic Sea is presented, together with some guiding criteria for their further selection and assessment. The implementation of adaptation measures and their monitoring is designed to be fully integrated into the main MSP process. Conclusions are finally reported in Chapter 6 and bibliographic references (literature and websites) are listed in Chapter 7.

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2. The Northern Adriatic area

The marine area covered by this report is the Northern Adriatic Sea. It both includes the territorial marine waters (within 12 nautical miles) facing four different administrative Italian regions (Friuli Venezia Giulia, Veneto, Emilia Romagna and Marche) and the offshore area that extends over the continental platform, until the median line that marks the boundary with Croatian and Slovenian waters. The area overlaps with four planning subareas identified in the Italian Maritime Plan for the Adriatic Sea (see Chapter 2), namely: A1, A2, A3, A4, and A7 (Figure 2). According to the MSP process, the delimitation of these four sub-areas was defined taking into account the administrative boundaries, the morphological and oceanographic characteristics, the distribution of uses and existing zoning for various planning and management activities.

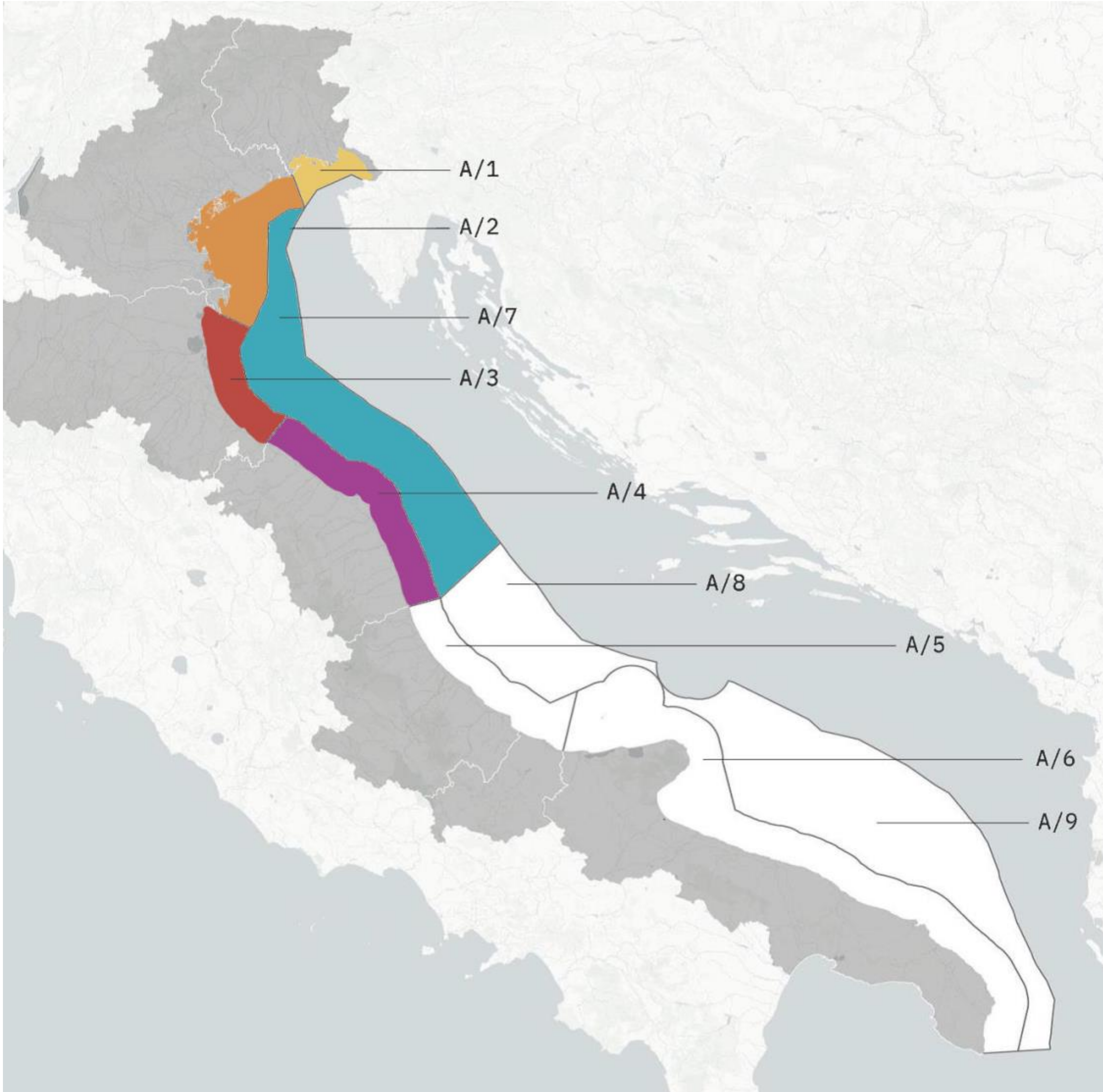

Figure 2. Planning subareas of the Italian Maritime Plan of the Adriatic Sea and the case study area

The Northern Adriatic area is a shallow enclosed sea area that extends over the largest continental shelf of the entire Mediterranean Sea. The sea bottom is mainly composed of muddy-detritic bottom of riverine origin and sandy seafloor. The overall homogeneity of the sea bed is interrupted by the presence of several calcareous outcrops (locally named “tegnue” or “trezze”) heterogeneously distributed and representing biodiversity hotspots.

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The coastal strip is predominately characterised by low elevation and sandy littorals, with a few exceptions as in the case of the Conero area in the Marche region or the rocky coast close to Trieste (Friuli Venezia Giulia). The coastal area also includes several transitional environments (lagoons, estuaries and deltas) with valuable habitats, hosting diverse species, functioning as critical spawning and nursery areas for fish, as well as wintering and breeding areas for birds. The area is also particularly prone to eutrophic processes due to relevant river flows (especially the Po River), delivering nutrients and organic matter, together with pollutants. The coastal area is highly urbanised, hosting several cities (Trieste, Venice, Ravenna, Rimini, Pesaro, Ancona) and numerous towns and villages, rich in diverse cultural heritage that, together with wide sandy beaches, plays an important role in the tourism economy.

The blue economy of the Northern Adriatic Sea is linked to a multitude of sectors. The most important ones are commercial and passenger transport (including cruise transport) and the related port activity, fisheries (small-scale and large-scale), shellfish aquaculture, tourism (coastal and maritime), mineral extraction (marine sand deposits) and oil and gas exploration and production.

Maritime traffic (passengers and goods, including oil products) has routes that mainly follow the south-north direction, referring to ports of strategic importance located in the northern area (Venice, Trieste, Monfalcone, Ravenna, Ancona on the Italian side). A Mandatory Ship Reporting System is in place (ADRIREP, IMO Maritime Resolution MSC No.139 (76) of Dec. 5, 2002) to monitor all ships passing through the Strait of Otranto, and thus controlling maritime traffic of dangerous and/or polluting goods. The ADRIREP rules are mandatory for all the ships belonging to one of the following categories: Oil tanker ships of 150 gross tonnages and above; Ships of 300 gross tonnages and above, carrying on board (as cargo) dangerous or polluting goods, in bulk or packages. Traffic Separation Schemes are also in place to regulate the high intensity of maritime traffic.

Fisheries is a deeply rooted activity in the Northern Adriatic Sea. The area is part of the GSA (Geographical Sub Area) 17, according to the spatial subdivision made by the General Fisheries Commission for the Mediterranean (GFCM). The majority of the Italian fishing fleet operates in the northern Adriatic area, where the coastal city of Chioggia owns the largest Italian fishing fleet (Farella et al., 2021). Small-scale coastal fishing (which uses small boats and makes daily trips) sums up to the fishing carried out by larger vessels which operate mainly using trawl nets, exploiting both demersal and pelagic resources. The fishery fleet operating in the Italian regions of the Northern Adriatic area has significantly decreased in the last twenty years, consistently with the national trend (Veneto Agricoltura, 2022). The specific sector of marine clam fisheries (*Chamelea gallina, Callista chione* in particular) is also intensively practiced, and represents an important, though decreasing, economic resource for the northern Adriatic area. In addition, marine recreational fisheries (MRF, shore and boat fishing) is another activity practised along the Italian Adriatic coast, causing additional pressure on fish stocks. Although complete and recent data are not available for quantitative analysis, a study (Pranovi et al., 2016) remarked on the need for including MRF in integrated coastal zone management and planning. The authors showed that the exploitation level caused by recreational fisheries can be significant, with MRF captures equal to 30% or 45% of the artisanal fishery in the same area, with some species, such as bluefish, bonito, pandora and picarel, showing larger values.

Mussel farming (*Mytilus galloprovincialis*) is the driving activity for the **aquaculture** of the Northern Adriatic area: long-line plants are distributed in all regions, due to the favourable trophic conditions. The clam farming sector (*Ruditapes philippinarum*) is another important aquaculture sector, especially relevant in deltas and lagoon areas of Friuli, Veneto and Emilia Romagna. Aquaculture in the case study area represents a traditional activity strongly rooted in the local culture. Decreasing or fluctuating trends for clam farming yields have been detected between 2012-2021, while increasing production of mussel farming is limited to some areas of the Po River Delta and along the coastal area of Emilia Romagna for the same period (Veneto Agricoltura, 2022), though affected by the covid-19 pandemics.

Tourism is a key sector of the Italian economy and one of the major activities in the study area, especially in summer. It combines several typologies of coastal (beach tourism) and maritime (cruise, recreational boating, yachting) tourism along with land-based tourism (coastal cultural heritage sites and cities). Less developed forms of tourism (niche tourism) include eco-tourism (in protected and high-natural value areas), recreational fishing and pesca-tourism.

Oil and gas activity in the Northern Adriatic area is almost entirely made by methane gas extraction in the marine areas of Emilia-Romagna and Marche regions. The production activity started declining after the peak of 13 billion cubic meters in 1994 (Muses Project, 2017). Despite the strong decline, the Emilia-Romagna Region is still the first region in Italy for the number of exploitation concessions and employment in the sector. Located off the coasts of Veneto, the Liquefied Natural Gas (LNG) terminal is an international hub connected to the mainland by a gas pipeline.

Finally, the research and exploitation of **underwater sand deposits** are particularly relevant in the study area. Ancient sand deposits created since the post-Wurm glacial era (around 18,000 years ago) were identified at different depths of the continental shelf. In the marine areas off Veneto, Emilia Romagna and Marche Regions, research activities suggest the presence of more than 600 Mm^3 of sand (Italian MSP plan for the Adriatic Sea, 2024). These deposits are receiving increasing attention for contrasting coastal erosion induced by sea level rise, due to their grain size and chemical quality which make them particularly suitable for beach nourishment.

All these sectors coexist with spatial conservation measures for **environmental protection**. Only one marine protected area (MPA) exists in the case study area, the Miramare MPA, near Trieste, at the northern-eastern edge of the Italian peninsula. However, several marine and coastal sites in the area are protected under the EU Natura 2000 network (Habitats and Birds EU directives). In particular, marine Natura 2000 sites are: (i) Friuli Venezia Giulia: ZSC Relitti di Posidonia close to Grado, ZSC Trezze di S. Pietro e Bardelli; (ii) Veneto: Tegnùe di Porto Falconera-Caorle (IT3250048), ZSC Tegnùe di Chioggia; (iii) SIC Adriatico Settentrionale extending across the Veneto and Emilia Romagna regions; (iv) Emilia Romagna: ZSC - Relitto della piattaforma Paguro (IT4070026). Moreover, three regional coastal parks are included in the areas, ensuring the protection of the Po river delta (Veneto and Emilia Romagna regional parks) and the Conero area (Marche Region).

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Figure 3. Natura 2000 sites in the Northern Adriatic area. Italian marine and partially marine sites are highlighted in light green. Source: EEA Natura 2000 viewer, latest access on 29.01.2024.

In addition to MPA, Natura 2000 sites and regional parks that are specifically designed for environmental protection, the Northern Adriatic area hosts other areas managed at the national level to preserve marine resources that are key for the long-term management of fisheries. These protection areas are the ZTB (Biological Protection Zones) of Miramare, Caorle (overlapping with the Natura 2000 site), Chioggia (overlapping with the Natura 2000 site), Fuori Ravenna and Barbare, established by the Ministry for Agriculture, Food and Forestry. In these areas, fishing is not completely banned but is strongly restricted to repopulate fish stocks. Moreover, trawling is banned within the 3-mile coastal strip.

Finally, other parts of the Northern Adriatic are internationally recognised for their environmental value, although not covered by specific conservation measures. The whole Northern Adriatic area is recognised as EBSA (Ecologically or Biologically Significant marine Area) according to the Convention for Biological Diversity and as IMMA (Important Marine Mammal Protected Area). A large part of the area is also defined as ISRA (Important Shark and Ray Area). All these areas host important habits and biodiversity which make them potentially relevant for conservation

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3. The MSP plan for the Northern Adriatic

3.1 Planning units and priorities

Italy has developed three MSP plans, one for each maritime region (Adriatic, Tyrrhenian and Ionian-Central Mediterranean). The MSP plans have been recently adopted through the Decree of the Ministry of Infrastructure and Transport on the 25th of September 2024[1].

Each maritime region is divided into planning subareas (9 for the Adriatic). The Northern Adriatic area covers five planning subareas. They correspond to the marine space adjacent to four coastal regions (Friuli Venezia Giulia – A1, Veneto – A2, Emilia Romagna – A3 and Marche – A4) and the offshore area that extends over the continental platform (A7). Planning subareas are further split into several planning units (6 units for A1, 9 units for A2, 11 units for A3, 12 units for A4 and 11 units for A7) where the Plan defines vocations according to one of the following options:

- Priority uses: a priority is assigned to a given use, but other uses can coexist in the same area;
- Reserved uses: one single use is allowed (typically military areas do not allow the coexistence of other uses for safety reasons);
- Limiting uses: a dominant use is assigned and this use can limit the development of other uses.
- Generic areas; planning units where any use is prioritised, reserved or considered as dominant.

The maps of the Northern Adriatic planning units and related use vocations are shown in Figure 4 and Figure 5.

[1] The adopted Italian MSP plans are available at https://www.sid.mit.gov.it/documenti-piano; last access on 09.10.2024.

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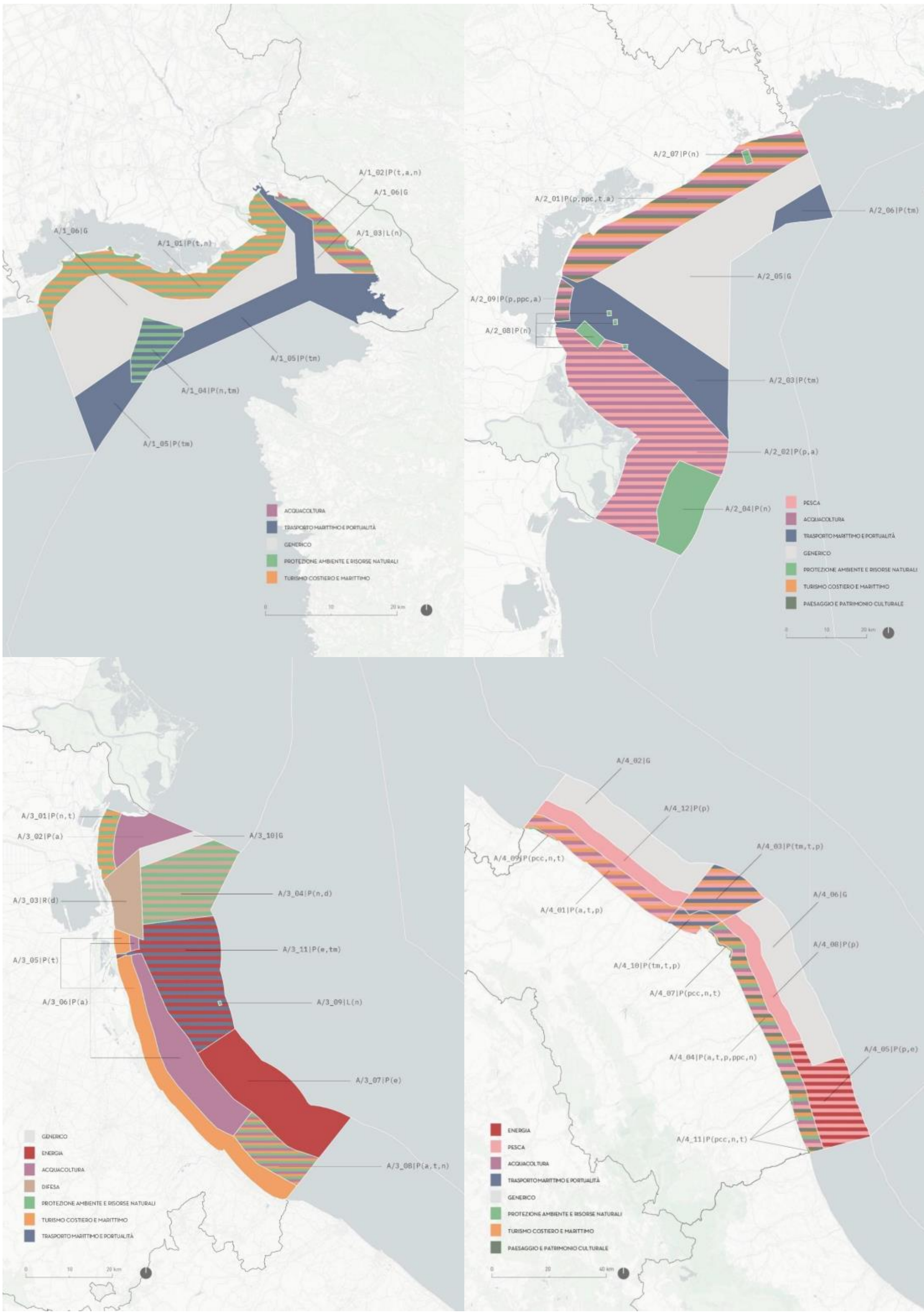

Figure 4. Planning units A1, A2, A3 and A4 of the Adriatic MSP plan for the Northern Adriatic Area. Source: Italian MSP plan for the Adriatic Maritime Areas, 2024 (https://www.sid.mit.gov.it/documenti-piano; last access on 09.10.2024).

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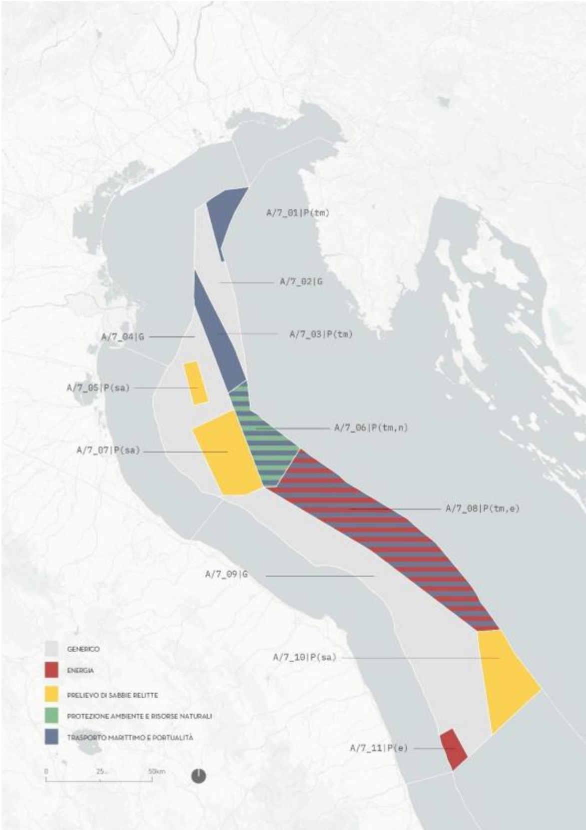

Figure 5. Planning unit A7 of the Adriatic MSP plan for the Northern Adriatic Area. Source: Italian MSP plan for the Adriatic Maritime Areas, 2024 (https://www.sid.mit.gov.it/documenti-piano; last access on 09.10.2024).

3.2 Climate change and the MSP plan for the Northern Adriatic area

Climate change adaptation is somehow addressed in the vision, strategic objectives, and cross-cutting measures of the Italian MSP plans. These elements tackle the considered topics of climate change adaptation in different ways:

- Anticipation of climate change effects
- Improved coastal protection and resilience
- Improved protection of biodiversity, habitats, and ecosystems.

Although climate change adaptation is reflected in the Italian (and Adriatic) MSP plan and several objectives and measures dealing with climate change adaptation were included, the real integration between the two policies is still limited. As emerged from previous analysis of this Project (MSP-GREEN deliverable D2.1; Cornet et al., 2023), this might be due to the hard challenges of formulating climate change scenarios, processing projections, dealing with uncertainties, identifying the most exposed and vulnerable areas and finally defining targeted spatial measures. The lack of operationalisation of adaptation measures for some maritime sectors such as fisheries and aquaculture, also played a role in limiting this integration. Though adaptation strategies have been explored and tools and approaches to foster adaptation in maritime sectors exist, specific examples of implementation of initiatives to address climate change impacts are generally lacking or are poorly reported as such. Measures are often undertaken to improve the sustainability of these sectors, with only indirect or non-explicit benefits in terms of adaptation.

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3.2.1 Strategic and specific objectives relevant to adaptation

The Italian MSP plan includes 44 strategic objectives dealing with several crosscutting and sector-based aspects relevant to the entire Italian marine space and therefore to its three maritime areas. A key strategic and crosscutting objective of the Italian MSP is "*OS_SS|03 – To contribute to the European Green Deal*", implicitly referring also to climate change adaptation as a key component of the EGD policy. *OS_SS|03* specifically targets the energy transition and the sustainability of maritime sectors (including fisheries and aquaculture), again linking to their progressive adaptation to climate. High implicit relevance for adaptation can also be found in those objectives approaching the nexus between adaptation and sustainability. The contribution of MSP to the sustainability of blue economic sectors and the national strategy of sustainable development is highlighted in two cross-cutting strategic objectives of the plan (*OS_SS|01; OS_SS|02*).

A well-known nexus with adaptation also exists for the strategic objective *OS_N|02* aiming to favour the extension of the protection of EU seas towards the 30% target (including 10% of strict protection) of the European Biodiversity Strategy. Marine protected areas (MPAs) and other effective area-based conservation measures (OECMs) are in fact effective measures to preserve marine ecosystems from climate change impacts, by increasing their health and resilience and ensuring "climate refugia" for the most threatened species.

Among strategic objectives set for specific sectors and uses, the strategic objective OS_DC|01 has specific relevance for adaptation in coastal areas. It aims *to favour the development, harmonisation and implementation of strategies and measures of coastal defence and to integrate the provisions already included in Flood management plans (Flood Directive), action plans for coastal areas and ICZM plans.* The objective explicitly pursues the need to respond to the increasing issues of coastal flooding and erosion that are worsened by the lack of sound programmes of interventions. Within the framework set by this objective, MSP intends to promote an integrated approach to the management of coastal areas that incorporates climate change issues into coastal defence programs and promotes integrated regional plans for adaptation. This is particularly relevant for the Adriatic, due to the high vulnerability of its coastline. In this regard, among its objectives, the Plan aims to adequately address the use and protection of the Adriatic submarine sand deposits, promoting their mapping and characterization. A sound management of sand marine deposits, as a non-renewable resource, is pursued to minimize the environmental impact and reduce conflicts with other uses.

Relating to the sector of cultural heritage, the strategic objective *OS_PPC|06 – To contrast illegal practices of building in coastal areas vulnerable to erosion and flooding* is relevant for adaptation since it aims to avoid building infrastructure in high-risk coastal areas exposed to erosion and flooding due to sea level rise. Additional and indirect links with adaptation can be identified in the following strategic objectives:

- OS_T|01: promoting sustainable forms of coastal and marine tourism. Ecotourism can be a livelihood alternative for coastal communities suffering from climate change risks while supporting the preservation of valuable ecosystems.
- OS_P|03: promoting, developing and spatial management of sustainable small-scale fisheries. The diversification of fisheries is an adaptation strategy to possible changes in the distribution of fish due to new climate conditions, respecting the principles of the Common Fisheries Policy.
- OS_A|02: supporting the process of definition of Allocated Zones for Aquaculture – AZA. Risk-based zoning and siting of marine aquaculture taking possible changes in habitat suitability of certain species is an adaptation strategy that can avoid possible economic losses).

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The strategic objectives (those mainly related to climate change adaptation are summarised in Table 1), considered as a whole, shape the vision of the national MSP. The vision assigns high priority to the contribution to the decarbonisation, contrast and adaptation to climate change, along with all issues of the Green Deal. Moreover, according to the vision of the plan, maritime activities are planned and managed in coordination with those planned and managed in the land part, specifically considering climate change challenges.

Strategic objective	Description
OS_SS|03	Contributing to the European Green Deal.
OS_N|02	Promoting the extension of the protection of EU seas towards the 30% target of the European Biodiversity Strategy, including 10% for strict protection.
OS_DC|01	Promoting the development, harmonisation and implementation of strategies and measures of coastal defence and integrating the provisions already included in Flood management plans (Flood Directive), action plans for coastal areas and ICZM plans.
OS_PPC|06	Contrasting illegal practices of building in coastal areas vulnerable to erosion and flooding.
OS_T|01	Promoting sustainable forms of coastal and marine tourism.
OS_P|03	Promoting, developing and spatially managing sustainable small-scale fisheries.
OS_A|02	Supporting the process of definition of Allocated Zones for Aquaculture – AZA.

Table 1. Main strategic objectives of the Italian MSP that are relevant for climate change adaptation. Source: Italian MSP plan for the Adriatic Maritime Areas, 2024 (https://www.sid.mit.gov.it/documenti-piano; last access on 09.10.2024).

3.2.2 Measures relevant to adaptation

Following the objectives reported above, the national plan identifies several measures that are also relevant for adaptation. Some of them have a national relevance, since they apply to all maritime areas, while some others specifically apply to Adriatic subareas.

The main MSP measure directly addressing climate change adaptation at the national level is the measure *NAZ_MIS|06*. It intends to develop a detailed study on the impacts of climate change on the MSP plans and the identification of related adaptation measures, to be considered in the mid-term assessment and revision of the MSP plans. The study shall adopt a multi-scale approach, dealing with the assessment and the identification of adaptation solutions at the level of the maritime areas, subareas, and planning units. The study will integrate the provisions of other plans (e.g., the National Plan for Climate Change Adaptation) and the outcome of other studies and assessments.

To allow full integration with the programme of measures established to implement the EU Marine Strategy Framework Directive, the measure *NAZ_MIS|15* establishes an "MSP-MSFD-Biodiversity Strategy-Fishery policy" working group linked to the activities of the Technical Committee for MSP. This group aims to identify the priority areas for the conservation of the environment and/or marine resources to expand the network of MPAs and/or sites of the Natura 2000 Network, in line with the provisions of the MSFD Directives, and to advance in the operationalisation of OECMs.

As already mentioned in the previous paragraph, benefits in terms of climate change adaptation are expected from the implementation of this measure. Other relevant measures include:

- *NAZ_MIS|70* aiming at reactivating the pre-existing “National Coastal Erosion Table” to address Integrated Coastal Zone Management in a coordinated way at the national level. Measures and research and experimental actions are promoted through the Table to adapt to climate change, also in synergy with mitigation objectives. Nature-based solutions and evidence-based actions, built on adequate scenarios are specifically mentioned.
- *NAZ_MIS|71* promoting improved coherence among other planning instruments or initiatives, such as existing ICZM/coastal strategies and plans, implemented projects on the coastal morphology (for conservation or restoration) and the contents of the MSP plan to implement corrective actions, also taking into account the most recent climate scenarios.
- *NAZ_MIS|72*, aiming to complete the mapping and the assessment of the quality and the quantification of the volumes of underwater sand deposits to properly plan their use, also in the perspective of increasing risk (due to climate change) of coastal erosion and flooding.
- *The NAZ_MIS|28*, aiming to integrate the data and information available within the national database on illegal buildings, to develop a study on the extent of infrastructure in the 300 metres wide coastal strip and, therefore, protect climate-sensitive coastal landscapes.

Examples of specific measures that contribute to adaptation are identified for some of the Adriatic subareas in the following table.

Subarea	Description
A1 (Friuli Venezia Giulia)	(A/1)_MIS|9. Mapping the distribution and assessing the quality of pre-coralligenous formations and seagrass meadows, to monitor their state of conservation, even outside protected areas.
A1 (Friuli Venezia Giulia)	(A/1)_MIS|16. Mapping and characterization of relict marine sand deposits for the creation of "functional beaches" for the safety of the coastal territories and the conservation of the specificities of the coast.
A1 (Friuli Venezia Giulia)	(A/1)_MIS|21. Implementation of national measures on coastal defence at the local level to address the Integrated Coastal Zone Management (ICZM) for the regional territory with an adaptive management approach.
A2 (Veneto)	(A/2)_MIS|13 and (A/2)_MIS|14. Actions to support small-scale fisheries and their sustainability.
A2 (Veneto)	(A/2)_MIS|16 Adopt a provision from the Regional Council to define the AZA (Allocated Zones for Aquaculture) in the sea, as macro-areas of eligibility for the issuing of concessions for aquaculture purposes.
A2 (Veneto)	(A/2)_MIS|17 (i) Update the document "Integrated Management of the Coastal Zone - Study and monitoring for the definition of coastal protection interventions from erosion in the Veneto Region - Guidelines" approved with DGR 898 of 14 June 2016; (ii) Allocate funds for coastal defence interventions (restoring coastal dune ecosystem and nourishment); (iii) promote multi-governance instruments for ICZM.

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Subarea	Description
A3 (Emilia Romagna)	(A/3)_MIS|1 Establish a working group aimed at regulating coastal defence, aquaculture and fishery in some coastal areas where there are needs for sand collection or disposal for coastal defence interventions and protection of nursery areas
A3 (Emilia Romagna)	(A/3)_MIS|2 Improve knowledge of offshore sand deposits which, for the Emilia-Romagna Region, represent the main external source of sand supply and strengthen data management tools (regional geoDB in_SAnd) following the provisions of the action C1.4 of the GIDAC regional strategy (Integrated management for the defence and adaptation of the coast to climate change).
A3 (Emilia Romagna)	(A/3)_MIS|6 Expand the SCI areas at sea and monitor the implementation of conservation measures of the Site of Community Interest (SCI) Northern Adriatic - Emilia-Romagna (IT4060018) and of the Special Area of Conservation (SAC) Wreck of the Paguro platform (IT4070026).

Table 2. Examples of adaptation measures identified at the regional scale. Source: Italian MSP plan for the Adriatic Maritime Areas, 2024 (https://www.sid.mit.gov.it/documenti-piano; last access on 09.10.2024).

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4. Climate change in the Northern Adriatic marine area

Climate change in the Northern Adriatic marine area needs to be analysed considering its connections with the whole Adriatic Sea and with the wider Mediterranean basin, a semi-enclosed and highly evaporative ocean basin, with oceanographic and orographic conditions that make it particularly vulnerable to climate change (Giorgi, 2006; Semia Cherif et al., 2020). Air and seawater temperature and heatwaves, salinity and acidification, as well as sea level rise and storminess, are the most relevant climate and sea state variables to be investigated to understand historical trends and future projections for designing a climate-proof Adriatic MSP. Some major insights from the available literature are presented in the following paragraphs, to provide context for the action presented in Chapter 5. A synthesis of the main topics addressed in the text is reported in Table 3. Impact chains, that illustrate the cascading effects of climate change on marine ecosystems and marine sectors and activities (including environmental protection) in the Northern Adriatic Sea are further presented in Chapter 5 as a knowledge basis for future assessments of climate change risks.

Climate hazard	Fisheries	Aquaculture	Tourism	Maritime Transport	Environmental protection
Increase in air temperature and heatwaves			Thermal discomfort of tourists Health risks during heatwaves Change in seasonality (extension of the favourable season for tourism)		
Increase in marine temperature and heatwaves Change in related chemical-physical conditions (salinity, oxygen and pH)	Change in habitat suitability Displacement of fishing grounds Mortality events of target fish and shellfish	Change in habitat suitability Mortality events of farmed fish and shellfish	Reduced bathing water quality and Bathing bans due to microbial and contamination Decrease in attractiveness of seabed habitats (diving)		Change in species composition Increased stress (and mortality events) of most vulnerable species Increased conservation efforts
Increased impacts from sea level rise and storminess	Increased danger in fish landing activities Flooding of coastal seafood processing structures	Increased danger in coastal operations Damage to long-line plants and other infrastructures Flooding of coastal seafood processing structures	Loss of beach areas Damage to tourism infrastructures Increased effort for coastal defence activities	Increased danger for port operations Flooding of port areas Service interruptions	Loss of intertidal coastal habitats

Climate hazard	Fisheries	Aquaculture	Tourism	Maritime Transport	Environmental protection
Precipitation change, with an increase in heavy rain events		Microbial contamination of farmed species	Reduced bathing water quality and bathing bans due to microbial contamination	Flooding of port areas Service interruptions	

Table 3. Synthesis of main climate change impacts on the main maritime sectors of the Northern Adriatic area.

4.1 Air Temperature and heatwaves

4.1.1 Historical trends and projections

The IPCC Sixth Assessment Report (IPCC, 2022), confirms the existence of unequivocal evidence of global climate warming, with changes observed in the atmosphere, oceans, cryosphere and biosphere. Accordingly, the available data (climate reconstructions, ground observations, reanalysis and remote sensing data) agree in highlighting the increase in temperature in the Mediterranean basin during the 20th century, with more accelerated warming in recent decades. According to the First Mediterranean Assessment Report (Semia Cherif et al., 2020) the average annual air temperatures in the most recent decade (2010-2020) reached a value of about 1.5°C higher than the pre-industrial period (1860-1890) with a likely uncertainty of +0.11°C. Consistently with what has been observed on a global scale, atmospheric warming in terrestrial areas (+1.8°C) is larger than that in marine areas. Quantitative estimations based on state-of-the-art EURO-CORDEX regional simulations suggest a robust and significant warming (+ 0.9-5.6°C depending on the emission scenario, RCP 2.6-RCP 8.5) of the mean annual temperature compared to the reference period (1980-1999) by 2100.

Following the global and Mediterranean warming trend, air temperatures are also increasing in the Northern Adriatic area. For the Veneto region, based on data from the meteorological stations distributed over the entire region (Regional Environmental Protection Agency, ARPAV[2]), a trend of +0.57°C per decade was calculated, considering the period between 1993 and 2022. Similarly, an overall trend between 0.56°C and 0.65°C per decade (over the period 1980-2015) was calculated for the Venice lagoon (Amos et al., 2017) by using data from meteorological stations in the historic city (1900-2000) and at the Venice airport (1950-2015). Similarly, over the Marche (Regional adaptation plan, Regione Marche, 2022) and Emilia Romagna (ARPAE - Regione Emilia Romagna, 2017) regions, an increasing trend of about +0.4°C per decade has been detected from the second half of the last century. Even though such time series are quite short to detect climate change signals and may be affected by short-term variability, they consistently suggest a clear warming over the whole area.

For the future, climate projections for the coastal area extending over a wide part of the Northern Adriatic Area (Veneto and Friuli Venezia Giulia coastal land area) suggest an increase of about 3.5°-3.6°C (winter) and of about 4.1-4.6°C (summer) by the end of the XXI century, considering a highly emissive scenario (RCP 8.5 scenario, values compared to 1976-2005, Regional climate platform for North-east Italy[3]). Considering a milder scenario (RCP 4.5), projected winter temperatures will increase by about 1.8°-1-9° by 2100 and about 1°C by 2050, while summer temperatures will increase by about 2.1°-2.2°C by 2100 and about 1.3-1.4°C by 2050. Analogue projections, referred to RCP 4.5 scenario and 2050, are also available for the Emilia Romagna region (Regional Climate Observatory[4]) and for the Marche region (Regional adaptation plan, Regione Marche, 2022), confirming a similar

[2] https://www.arpa.veneto.it/temi-ambientali/cambiamenti-climatici/il-clima-in-veneto; last access on 29.01.2024
[3] https://clima.arpa.veneto.it/; last access April 2024
[4] https://www.arpae.it/it/temi-ambientali/clima/previsioni-e-proiezioni/proiezioni-climatiche/proiezioni-climatiche-in-emilia-romagna; last access April 2024

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warming trend over the whole area.

In addition to mean annual and seasonal temperature, large parts of the Mediterranean will experiment an increase in the number of tropical nights, especially in summer. Over a large part of North-eastern Italy, the annual number of tropical nights is projected to increase up to 84 by 2100 considering the worst scenario (RCP 8.5[5]). The frequency and severity of heat waves will also increase (Lionello & Scarascia, 2018; Semia Cherif et al., 2020).

4.1.2 Risks for marittime sectors

These long-term changes in air temperature, including tropical nights and heatwaves are expected to generate thermal discomfort for visitors or even health risks, especially for the most vulnerable people like the elderly or children, likely affecting tourism destinations along the Adriatic coast. A recent study investigated the possible changes in tourism fluxes for a coastal town located in the Emilia Romagna region (Misano Adriatico). Results indicate that overnight stays and arrivals are expected to decrease under medium to high emission scenarios (SSP4 - RCP4.5 /SSP5-RCP 8.5) generating economic losses for the tourism sector. However, the different adaptation capacities of the suppliers in the area (tourist areas, hotels, etc.) can also generate different responses and different variations in tourist overnight stays (Cavallaro et al., 2021).

Conversely, longer-lasting favourable seasons in combination with the continuing growing number of tourists, will increase the demand for marine space in the Adriatic region for diverse touristic activities directly occurring at sea. This aspect shall be recognised and taken into consideration by MSP plans. Leisure boaters' destinations often overlap with ecologically significant areas, including MPAs and marine Natura 2000 sites. The crucial role of MSP has been recognised within the Pharos4MPAs project (Carreño et al., 2019) which provides recommendations for MSP authorities to prevent or minimize the impacts of leisure boating in such areas.

4.2 Seawater temperature and marine heatwaves and water quality parameters

4.2.1 Historical trends and projections

The IPCC's sixth Assessment Report considers "virtually certain" that global sea surface temperatures have risen since the beginning of the 20th century. It is very likely that the average sea surface temperature varied by +0.88°C between 1850-1900 and 2011-2020 and that a variation of approximately 0.6° occurred between 1980 and 2020. Different regional patterns show large variations from the global trend.
According to the summary of the First Mediterranean Assessment Report (Semia Cherif et al., 2020), the warming of the surface of the Mediterranean Sea can be considered on average between +0.29 and +0.44°C per decade, depending on the period investigated and the reference datasets. The eastern Mediterranean basin is experiencing the highest temperature variations, as observed in some recent studies (Pisano et al., 2020, 0.048°C/year in the Levantine and Aegean basin between 1982 and 2018). A graph of the increasing trend in sea surface temperature distribution over the Mediterranean is provided by the Copernicus Marine Service for the most recent period (1993-2022, Figure 6)

The Adriatic Sea is also affected by temperature increase. The analysis of data limited to the period 1993-2017 (Mohamed et al., 2019) suggests the presence of a trend equal to 0.35°C per decade, aligned with the one referred to the whole Mediterranean basin. A very similar trend (0.33°C per

[5] https://clima.arpa.veneto.it/; last access April 2024

decade, 1980-2010) has been found for the Northern Adriatic area, by processing data from satellite (HadSST1.1) measurements (Amos et al., 2017). As regards future evolution, the Northern Adriatic area is expected to follow the expected trend investigated for the Mediterranean area. According to the most recent studies which consider four regional models (MED-CORDEX), the average surface temperature would increase by approximately 1.9°C by 2050 and 3.9°C by 2100, according to a high emission scenario (SSP5-RCP 8.5) (IPCC WG1 interactive Atlas).

At the same time, particularly hot periods (marine heat waves) have become more frequent, more intense and spatially more widespread in recent decades in the whole Mediterranean, including the Adriatic Sea (Juza et al., 2022). The most important heat waves, which have occurred since 1982, occurred in 2003, 2012, 2015 and 2017 (Semia Cherif et al., 2020), due to a combination of various factors (particularly high atmospheric temperatures, wind calm periods and reduced heat exchange across the sea surface, Darmaraki et al., 2019). The effects of future marine heatwaves are still poorly investigated and need to be assessed considering future temperature data distribution and future altered biological community composition that could have different tolerance ranges to extreme temperatures.

Due to its shallow depth, the Adriatic Sea, and the northern sub-basin in particular, experiences strong temperature fluctuations, reaching extremely low temperatures in winter and warming up like the southern sub-basin in summer (Cavraro et al., 2022). In addition, dense-water masses originate in the North Adriatic (NAdDW) through winter cooling and evaporation of shelf waters associated with local wind forcing (bora wind events). The NAdDW flows across the southern Adriatic margin slope and represents the densest water in the entire Mediterranean. It is relevant for the water circulation in the whole basin and for the associated nutrient towards the southern basin. Increasing sea temperature due to climate change, may alter the formation of cold and dense water masses, altering the biogeochemical balance of the basin. Under a severe climate change scenario (RCP 8.5), the projected dense water formation may reduce by 75% for the Adriatic Sea, 84% for the Aegean Sea and 83% for the Levantine Sea (where other dense water masses originate) by the end of the century (Parras-Berrocal et al., 2023).

In addition, lagoon environments that feature the Northern Adriatic coast will amplify the temperature changes expected for the Adriatic Sea, especially in the shallow tidal flats where the intensity of the marine heat waves will be more than four times larger than that in the open sea (Ferrarin et al., 2024).

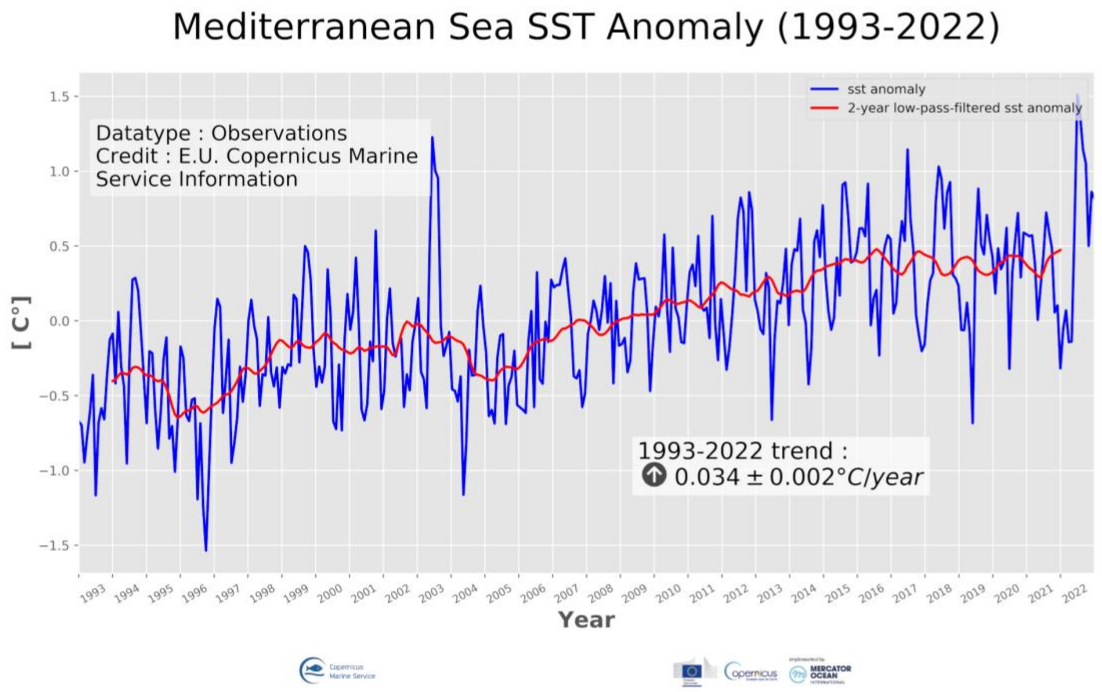

Figure 6. Time series of monthly mean (blue line) and 24-month filtered (red line) sea surface temperature anomalies in the Mediterranean Sea during the period 1993-2022. Anomalies are relative to the climatological period 1993-2014. Source: Copernicus marine service, https://marine.copernicus.eu/access-data/ocean-monitoring-indicators/mediterranean-sea-surface-temperature-time-series-and-trend (last access April 2024).

4.2.2 Impacts on water quality

The increasing seawater temperature has multiple cascading effects on water quality. Acidification, deoxygenation and bacterial growth are well-described impacts of climate change. In the Mediterranean sea, a recent study (Reale et al., 2022) investigated these changes under two emission scenarios, showing stronger impacts in the RCP8.5 (worst-case) scenario compared to RCP 4.5 and, in particular, in the eastern Mediterranean due to the more limited influence of the exchanges in the Strait of Gibraltar in that part of the basin. Basin-wide deoxygenation tendencies are found in both scenarios, due to lower oxygen solubility (related to temperature increase) and to changes in the thermohaline circulation of the basin. The overall accumulation of CO_2 in the basin results in the acidification of the Mediterranean water, with an overall decrease in pH, dependent on the different ventilations and residence times of the water masses as well as the exchanges in the Strait of Gibraltar. A tendency to recover towards the values observed at the beginning of the 21st century for several biogeochemical variables was also observed after 2050, under the moderate emission scenario (RCP 4.5).

In addition, the Northern part of the Adriatic basin and the Italian continental shelf were found to be particularly affected by cumulating impacts both caused by climate change (RCP 8.5 scenario) and by different economic activities (Furlan et al., 2019). This is due to the high concentration of human activities in the area, the rapidly changing seawater conditions and the presence of vulnerable benthic habitats. Highly affected areas are mainly located around the Po Delta River and the ports of Trieste and Venice due to the high nutrient input, as well as the intense shipping traffic and port activities in these areas.

4.2.3 Risks for marine ecosystems and maritime sectors

The impacts of increasing temperature, marine heatwaves and changing ocean conditions on marine ecosystems have been documented worldwide, including biodiversity reduction and tropicalisation of marine communities (Darmaraki et al., 2019). The effects on environmental protection, fisheries, aquaculture and tourism are well recognised as well, even though quantitative assessments tailored to the Northern Adriatic Sea are scarce.

Concerning environmental protection in the Northern Adriatic area, coralligenous conservation can be particularly challenging. Coralligenous outcrops are scattered on the sandy-muddy seabed of the area (locally referred to as "Tegnue") and are recognised to be extremely important for diverse benthic communities and as nursery areas for numerous fish species, thus representing sites of high local interest both for fisheries and for diving (Vitelletti et al., 2023). According to the authors, sea salinity, temperature, and nitrate concentration are the most relevant variables in affecting the coralligenous outcrops distribution. The environmental variations projected under a severe climate change scenario (RCP 8.5) are expected to favour the spreading of opportunistic organisms, more tolerant to stressful conditions, while calcareous species and organisms more vulnerable to environmental alterations might undergo a decrease in their suitable habitat. In general, about 62% of the protected marine surface of the overall Mediterranean was found to be potentially at risk from climate change, having a low/very low climatic stability (Kyprioti et al., 2021).

Seagrass species are also at risk from climate change. In the Northern Adriatic Sea, five species have been documented (Curiel et al., 2021). Along coastal zones and in transitional environments, *Cymodocea nodosa*, *Zostera marina*, *Zostera noltei* and *Ruppia maritima* (the latter species in most confined areas and brackish lagoons) can be found. *Posidonia oceanica* is also present, with limited patches (e.g. Gulf of Trieste) due to its high sensitivity to turbidity, siltation and anthropization. No specific studies about the effect of climate change on the distribution of marine seagrasses in the North Adriatic have been found and difficulties in distinguishing the effects produced by seawater warming from those produced by other anthropogenic stressors have been reported (Chefaoui et al., 2018). However, thermal anomalies (coupled with other pressures, like coastal urbanisation and tourism) were revealed to be a significant driver that can explain important meadow losses or switch in meadow composition, as found in a marine area in front of Marche region (Danovaro et al., 2020). Ecological niche modelling (ENM) was used to project the future distributions of seagrasses in the whole Mediterranean, under two climate change scenarios (RCP 2.6 and RCP 8.5). Sea surface temperature and salinity were used to investigate habitat changes. Results indicated an overall significant population decline and genetic loss of *Posidonia oceanica* and *Cymodocea nodosa*, but also areas with stable or gained habitat, especially for *Cymodocea nodosa* (Figure 7).

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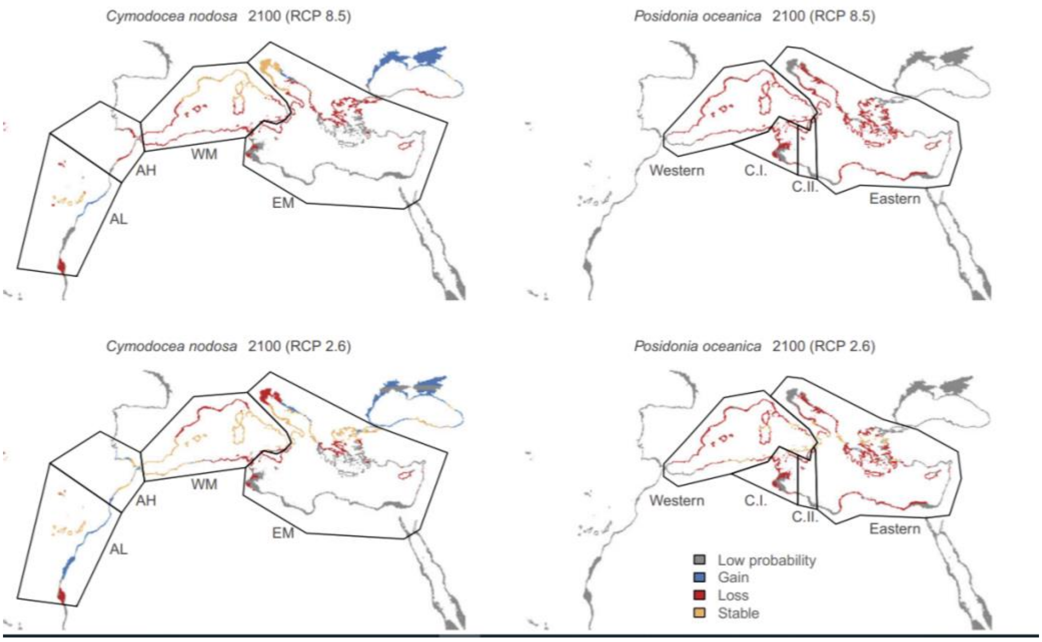

Figure 7. Simulated habitat changes under different scenarios (RCP 2.6 and RCP 8.5) by 2100 for Posidonia oceanica and Cymodocea nodosa. The maps show the future loss, stable, and gained habitat.

The impacts on Adriatic fisheries depend on the climatic and geomorphological features of the Adriatic Sea that prevent fish species from moving to higher latitudes to escape the increasing warming of waters (being semi-enclosed, "cul-de-sac" basin), and prevent them from finding refuge in cold deep waters, as the basin is very shallow (Cavraro et al., 2022; CIESM, 2018). In a recent paper (Cavraro et al., 2022), the effect of two climate change scenarios (RCP 4.5 and RCP 8.5) on habitat suitability was investigated for several nektonic species targeted by the small-scale fisheries of the GSA 17. Habitat suitability in the Northern and Central Adriatic Sea was found to decrease for nearly half of the species considered, with a decrease in landings from 13.5% to 86.9%, depending on the scenario. The only species expected to increase under the effect of climate change is *Callinectes sapidus* (blue crab), a non-autochthonous and extremely voracious species that is already disrupting local species (*Tapes sp.; Mytilus sp*.) with devastating effects on fisheries and aquaculture sectors, as already recently complained by several bivalve rearing associations operating in the coastal areas of Veneto and Emilia Romagna.

The effect of seawater warming on the bivalve rearing activity is being already experienced in the Northern Adriatic area, with repeated mortality events of mussels and clams occurring during summer heatwaves and related anoxia events. As found in a recent study focussed on the Venice Lagoon and based on landscape tolerance models in an RCP 8.5 climate change scenario, the effects of heatwaves on the mussel *Mytilus galloprovincialis* and the clam *Ruditapes philippinarum* can cause important mortality events. The tolerance model predicts the occurrence of a 50% mortality event (LT50) based on the exposure time at a given temperature. Results show that lethal heatwaves for both species (in terms of LT50) may frequently occur in future conditions, starting from the 2070s. This is expected to generate important economic losses to the Italian farming sector: based on local production data (Veneto Agricoltura, 2022), a loss of 50% of production could correspond to a loss of 15000 tonnes or €75 million, of which €1.3 million come from the Venice Lagoon (Bertolini et al., 2023).

The effects on tourism, though not specifically investigated in the case study area, are likely to deteriorate bathing water quality (pathogenic micro-organisms, higher microbial activity, new survival range of toxic and invasive species) and contribute to the loss of biodiversity of the seabed, with a reduced attractiveness of destinations, especially for bathing and diving tourism. This might be

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particularly relevant whenever it sums up the thermal discomfort related to increasing air summer temperatures, heatwaves and tropical nights.

4.3 Sea level rise and storminess

4.3.1 Historical trends and projections for sea level rise

Clear experimental evidences show that the global average sea level has been rising from the twentieth century to the present day (high degree of confidence, IPCC, 2021). From 1901 to 2018, the average global sea level rose by 0.20 m (uncertainty range between 0.15 and 0.25 m), with an average rate of 1.73 mm/year. Considering the most recent period (2006-2018), the measurements (satellite measurements) highlight an overall variation of 4.4 cm, corresponding to a growth rate (3.69 mm/year) more than double that calculated starting from 1901.

The hydrodynamic connection of the Mediterranean Sea to the ocean through the Strait of Gibraltar determines that changes in sea level in the nearby Atlantic can be rapidly transferred to the Mediterranean and vice versa, tending towards a situation of equilibrium between the two domains. However, variations can occur (generally within a few centimetres; Sannino et al., 2022) between the Mediterranean and Atlantic sea levels, as an effect of salinity changes and atmospheric driving forces (wind and pressure). Considering the most recent period, based on satellite altimetry data, a linear trend equal to 2.8 ± 0.1 mm/year between 1993 and 2018 (Semia Cherif et al., 2020) was reported for the Mediterranean Sea, in line but slightly lower than the global rate for the same period, equal to 3.25 [2.88-3.61] mm/year. Significant anomalies compared to the global average are particularly found in the eastern part of the basin (including the Adriatic basin), but complex dynamics also characterize the western part, strongly influenced by exchanges with the Atlantic Ocean through the Strait of Gibraltar.

The relative sea level rate in the Northern Adriatic area is also strongly affected by land subsidence, particularly relevant along the whole coastal area of Veneto and Emilia Romagna region. High rates of subsidence were recorded during the 1960s due to anthropogenic activities of groundwater and natural gas extraction. The recent pattern of vertical GPS rates for vertical land motion along the coast of the Northern Adriatic Sea is highly variable, being almost null in the Gulf of Trieste, but ranging from 0.9 to 4.9 mm/y (various historical periods, between 2008 and 2018) in the coastal area from Venice to Ravenna, with an average value of 3.30 ±0.85 mm/y (Vecchio et al., 2019). The same authors used these rates to project future relative sea level (compared to 2005) in the Northern Adriatic area, suggesting:

- for the area around Venice, a range between (cm) + 28±10 (RCP 2.6) and + 31±11 (RCP 8.5) by 2050 and from 60 ± 22 (RCP 2.6) to 82±26 (RCP8.5) by 2100;
- for the area around Trieste, a range between (cm) 14 ±8 (RCP 2.6) and 15±9 (RCP 8.5) by 2050 and from 34±20 to 52 ± 24 (RCP 8.5) by 2100.

High-definition submersion maps (Figure 8) based on another model that includes eustatic projections for 2100 (IPCC RCP 8.5 scenario and extreme scenario (Rahmstorf, 2007), glacial-hydrostatic values and tectonic vertical movement were also provided (Antonioli et al., 2017), suggesting for the coastal area from Marano-Grado (Friuli Venezia Giulia) to Ravenna (Emilia Romagna) higher relative sea level rise, up to 101 cm (RCP 8.5, maximum value) and to 143 cm (Rahmstorf scenario) by 2100.

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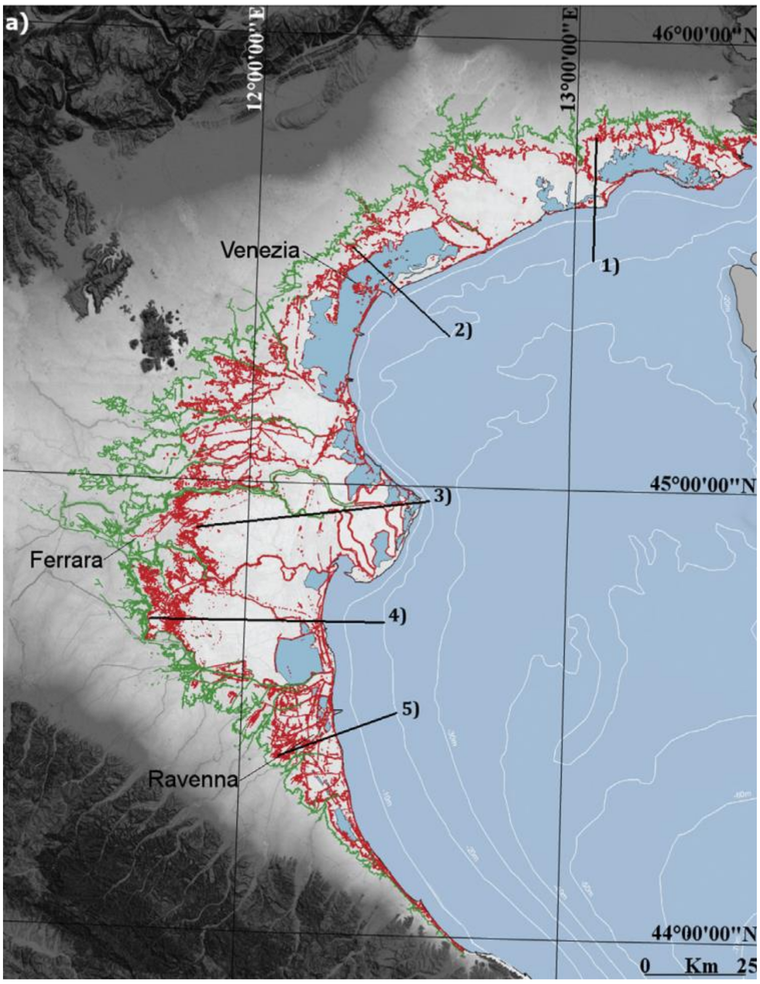

Figure 8. Expected coastlines for 2100 in the investigated areas for the North Adriatic by 2100 for the Rahmstorf scenarios (2007, red line). The 5 m contour line is shown in green. Source: Antonioli et al., 2017.

4.3.2 Historical trends and projections for winds, waves and storms

While sea level rise is a quite certain phenomenon in the case study area, following global trends, less data and more uncertain assessments characterise historical trends and future projections for winds, storminess and waves, both for the Mediterranean and for the Adriatic Sea.

In the Mediterranean basin, consistently with the reduction in winds, an overall reduction in storminess has been suggested by several authors, although the effects in terms of waves are rather uncertain and locally variable, with even opposite trends suggested by some authors (Caloiero et al., 2022) or with inadequate evidence to provide robust projections for the future period (Bonaldo et al., 2020). There is a generalized reduction in significant wave height for large areas of the Mediterranean (De Leo et al., 2021; Semia Cherif et al., 2020), especially in winter. Similarly, a decrease in the number and intensity of extreme values is expected (Denamiel et al., 2020; Semia Cherif et al., 2020).

As regards the northern Adriatic, some evidence (historical series of wave data at the Acqua Alta Platform, located 15 km away from the coast of Venice, and modelling simulations for the next century) suggests that climate change is producing a different response in the sea state associated with the two dominating winds of the area: bora (from Northeast) and scirocco (from Southeast) (Bonaldo et al., 2020; Pomaro et al., 2017, 2018). Such studies indicate for the historical period (1979-2015) a significant decrease in wave height (Hs) associated with the bora and a less evident variation in Hs linked to the sirocco, with a certain tendency for the latter to increase in frequency of the average values. Accordingly, no increasing trend in the frequency of storminess had been found by previous research studies (Lionello et al., 2012).

For the future climate, state-of-the-art research suggests that the change in frequency, intensity, annual cycle, and spatial structure of the wind inducing the Adriatic storm surges will be small (Međugorac et al., 2021). Climate change may generate a slight, though uncertain, trend towards decreasing wind-generated waves, particularly those associated with the bora wind. Greater uncertainties characterize the variations in the wave climate associated with the sirocco. The comparison between future scenarios and the historical period (Ruol, 2022) shows a possible decrease in the significant height of the waves, especially considering the 99^{th} percentile of the data. The reduction is of the order of -3-6% in the RCP 4.5 scenario and 5-10% in the RCP 8.5 scenario and appears more accentuated in the northern part of the basin. A similar decrease also concerns the significant wave height associated with extreme events (storms with a return time of 30 years).

The conclusions of the various studies therefore suggest that in the next decades wave and storm surge maxima will decrease while thermosteric expansion and water mass addition through the Gibraltar Strait will increase mean sea level. In the end, sea level remains the dominant forcing and determines an increase of the maximum water level along most of the coastline of the Mediterranean (Lionello et al., 2017).

4.3.3 Risks for maritime sectors

Among the MSP sectors of the North-Adriatic area, sea level rise is expected to mainly impact coastal tourism and related coastal defence activities, as well as ports.

Concerning coastal tourism and coastal defence activities, a higher need for sand for beach nourishment will be needed, with increasing sediment extraction from source sites and increasing pressure on marine relict sand deposits. The increasing demand for new dredging sites at sea to obtain sand for beach nourishment and improve the adaptation of coastal areas is an important MSP challenge. This resource is limited and conflicting interactions between sand dredging and other maritime activities and environmental protection of benthic habitats and species can arise. MSP has an important role in planning the correct use of dredging areas (EU MSP Platform, 2018) avoiding conflicts with other uses, allocating priorities and ensuring better management of resources. The need to evaluate offshore sand deposit availability for beach nourishment was highlighted and investigated within the SUPREME project (SUPREME project, 2018), specifically for the North Adriatic case study area. The analysis identified possible conflicts, especially in the presence of Oil & Gas concessions, extraction platforms and related pipelines and maritime transport routes.

Inundation due to sea-level rise and storm surges could cause both temporary and permanent flooding of seaports, with potential disruption of port operations and effects on the hinterland in Europe and on the foreland worldwide. Considering extreme sea level projections under RCP4.5 and RCP8.5 a large number of European ports will be at risk. The ports located along the north-western Adriatic coast are classified at medium-high risk for the hinterland effects. Further impacts could also involve the interruptions of road-, rail- and inland waterway networks (Christodoulou et al., 2019).

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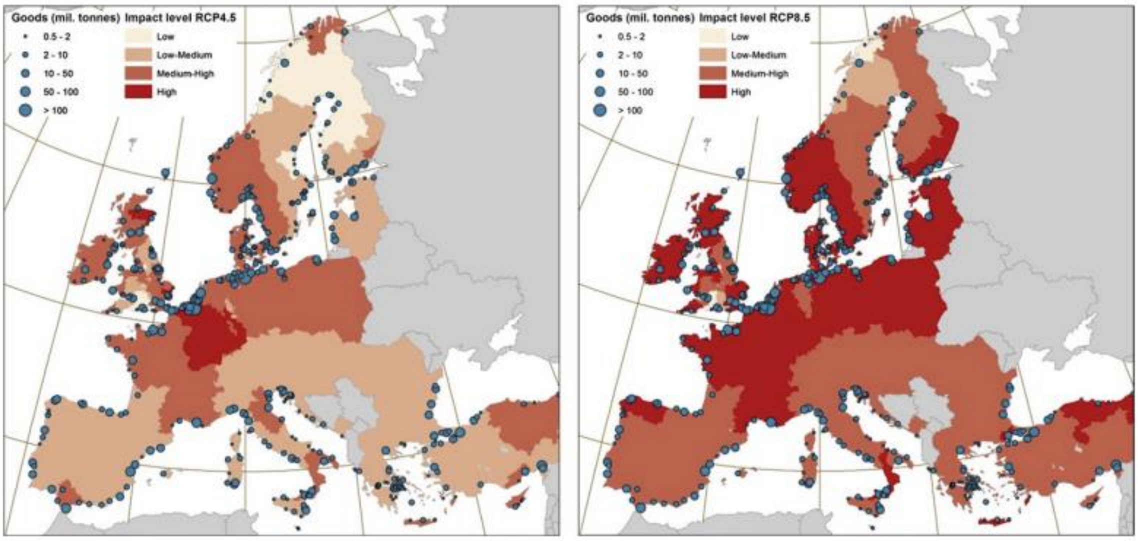

Figure 9. Impacts of the ports affected by extreme sea level rise (100-year) increase from 2010 to 2100 on hinterlands (NUTS 3 regions) according to RCP 4.5 (left) and RCP 8.5 (right). Source: Christodoulou et al., 2019.

4.4 Precipitation and river runoff

4.4.1 Historical trends and projections

The IPCC's sixth assessment report (AR6) identifies a probable increase in total precipitation (terrestrial part of the globe) starting from the second half of the last century (medium confidence) with a faster increase starting from 1980. However, the report also remarks the presence of large interannual and spatial heterogeneity, with even opposed trends in different regions. In this regard, the Mediterranean region is experiencing an overall decreasing trend in precipitation, with future projections that likely suggest further decreases in large parts of the region by the end of the century, despite wide uncertainties and high spatial variability (Semia Cherif et al., 2020).

Over the territory (land area) that faces the Northern Adriatic Sea, historic precipitation series do not reveal clear and consistent trends. Heterogeneous patterns are also observed considering seasonal data instead of annual data, and different periods. Future projections reflect the uncertainty of historical analysis with higher discrepancies between different models. Moreover, the comparability of different information sources referring to different regions of the Northern Adriatic Sea is limited due to the different indicators selected for projections, different reference periods and future horizon times as well as the use of annual versus seasonal averages.

Over Veneto and Friuli Venezia Giulia (Regional climate platform for North-east Italy), some signals of change are expected under RCP 8.5, with an increase in winter and autumn precipitation and a decrease in summer precipitation at the end of the century, both considering the daily value and the extreme precipitation (values above the 95th percentile of the reference period). Moreover, as reported in a study focussed on Friuli Venezia Giulia (ARPA Friuli Venezia Giulia, 2018), while the magnitude of the change in heavy precipitation is in line with that of the average precipitation, the change in the number of days with intense precipitation is lower. This means that on average the intensity of the individual events extremes tends to vary more markedly. In parallel, different simulations agree on an increase in the number of dry days and/or consecutive dry days, especially in summer. This evidence is reported over Veneto and Friuli Venezia Giulia (Regional climate platform for North-east Italy) Emilia Romagna (ARPAE[6]) and Marche region (Marche region, 2022).

Precipitation changes, together with snowmelt dynamics, land use changes and different water management practices, affect freshwater inflow from rivers. In turn river discharge significantly impacts the oceanographic and biogeochemical properties of the Adriatic Sea (Ricci et al., 2022), with special reference to the Northern area (Sani et al., 2024) where major rivers flow (including Po, the longest Italian river). A substantial decline in runoff of major rivers (Po, Adige, Brenta, Piave, Isonzo, and the rivers along the Slovenian Coast) was observed in the long period, although alternating periods of increasing and decreasing discharges in the Po River were also detected (Sani et al., 2024). Despite decreasing trends in total water discharge, the increase in the frequency and severity of extreme precipitation events is expected to cause abrupt changes in river water level and discharge, with associated floods and impacts on seawater quality, especially along the coastal strip.

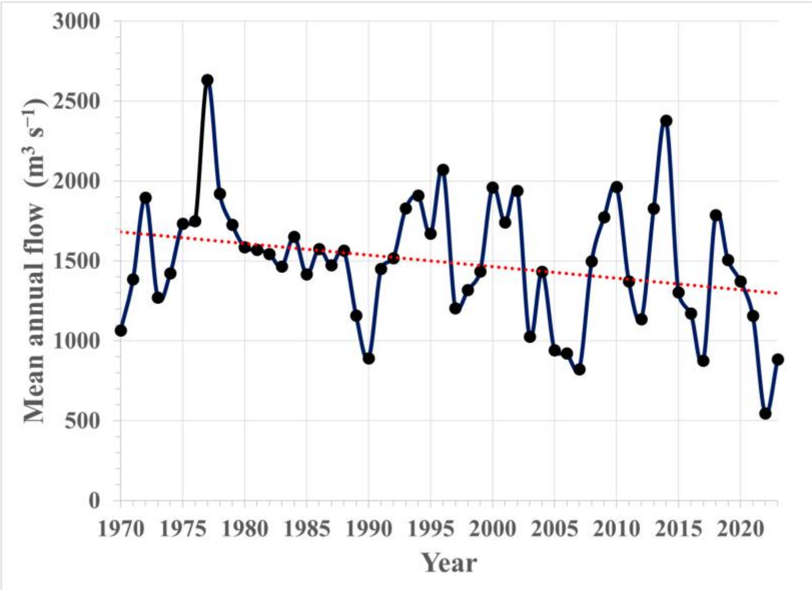

Figure 10. Long-term trends in the daily discharge of the Po River (m^3s^{-1}) from January 1970 to October 2023, with a significant linear regression. Data sourced from the Pontelagoscuro station and provided by the Hydro-Meteorological Service of the Regional Agency for Environmental Protection of Emilia-Romagna Region (ARPAE-ER). Source: Sani et al., 2024.

4.4.2 Risks for maritime sectors

Heavy precipitations generate pressure on stormwater collection systems of urban areas and may determine the overflow of untreated water into the sea. The most severe effects are expected for combined sewage systems, which both collect sanitary sewage and rainwater. Moreover, precipitation peaks (especially after long dry periods) deliver polluted surface runoff from urban and agricultural areas to the water bodies and the sea.

Several studies indicate that faecal indicator bacteria concentrations tend to increase during wet weather conditions, and a positive correlation between faecal indicator with precipitation and water temperature was found (Penna et al., 2023). The consequential effects on water quality are detrimental especially for coastal tourism (poor bathing water quality, with possible bans due to microbial contamination) and for aquaculture, with possible impacts on human health due to consumption of microbiologically contaminated products.

[6] https://www.arpae.it/it/temi-ambientali/clima/previsioni-e-proiezioni/proiezioni-climatiche/proiezioni-climatiche-in-emilia-romagna; last access April 2024

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The microbial contamination of Adriatic seawater after heavy precipitation events have been modelled in several locations of the western and eastern coasts (Ferrarin et al., 2021; Penna et al., 2023). Simulations led to realistic representations of the *Escherichia coli* distribution in the nearshore waters, describing the marked decrease in the bacteria concentration from the river mouth towards the open sea, due to the effect of dilution with sea waters and decay induced by solar radiation and salinity. In the Fano-Arzilla site (Marche region), the distribution of *E. coli* plume for specific pollution events that occurred in summer 2020 revealed to be constrained by the breakwater and artificial reefs which directed the flow of polluted waters towards the beaches. This caused the exceedance of the threshold for bathing water quality (500 CFU 100 mL). The temporal evolution of E.coli concentration was also strongly modulated by tidal action, with peak values occurring during low tide (Ferrarin et al., 2021).

The severity of microbial contamination during heavy precipitation events is also documented in Emilia Romagna region. The coastal town of Rimini (where bathing tourism is strongly present) is implementing the so-called "Optimized Seawater Protection Plan" to address the increasing bathing bans due to microbial contamination following increasing heavy precipitation events. The plan aims to provide the municipality with a renewed and upgraded sewage system and wastewater treatment plant, increasing and improving collection and treatment capacities in the whole area.

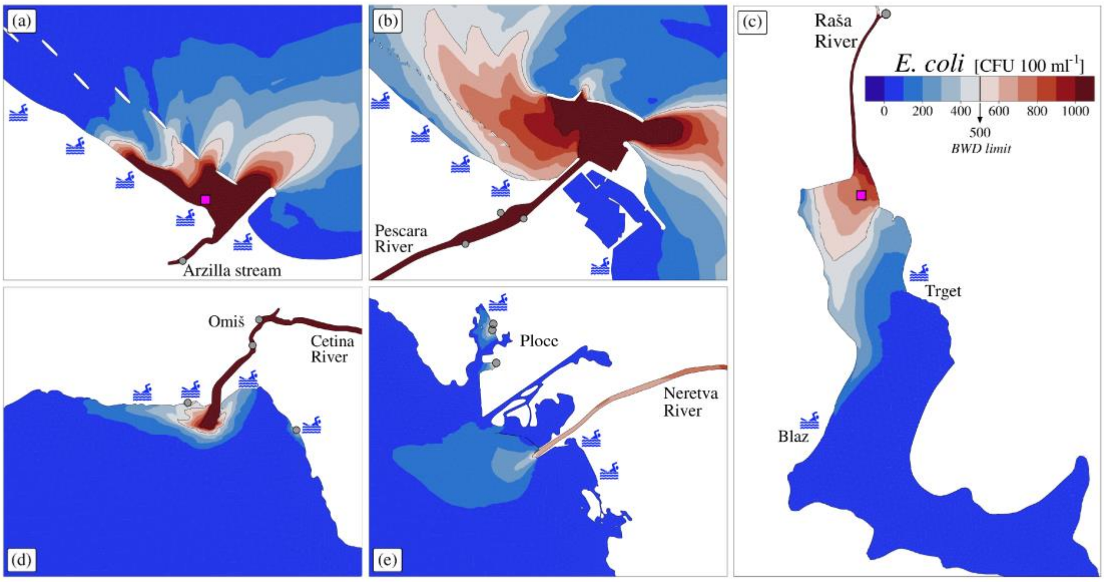

Figure 11. Maximum surface E. coli concentration maps in the five study areas (July–September 2020) along the western (including the Arzilla stream in the Marche region) and eastern coasts of the Adriatic Sea. The grey dots mark the point sources and the magenta squares mark the control stations; the swimming symbols indicate the bathing locations. Source: Ferrarin et al., 2021.

5. Towards an Adriatic climate-proof MSP

The overview of climate change impacts on the Northern Adriatic basin (chapter 4) shows that this area is particularly vulnerable to climate changes which can affect important economic activities as well as key habitats and species. The current Italian Adriatic MSP plan only partially addresses climate change and integrates objectives and measures specifically dedicated to these aspects (chapter 3). As remarked by the same MSP plan, it appears fundamental to improve climate change integration into the plan to make it fully climate-proof.

In this regard, a new action to make the MSP plan of the Northern Adriatic fully proofed is designed and proposed in this report. This action refers to the "Adaptation policy cycle" endorsed by the European Environment Agency (European Environment Agency, 2018) and operationalised in 6 steps in the Adaptation Support tool of Climate-ADAPT (the reference platform for climate change adaptation for the European Union, according to the 2021 EU Adaptation Strategy (COM(2021) 82 final)). The 6 steps aim to (1) prepare the ground for adaptation, (2) explore risks and vulnerability to the current and future climate risks, (3- 4) identify and assess adaptation options, (5-6) implement, monitor and evaluate its results.

5.1 Preparing the ground for adaptation

5.1.1 Gaining the political support and setting up the process

The first step of the action is setting up the multi-level governance framework and the organisation of the whole adaptation process. In this step, relevant authorities need to be identified and engaged, to gain political support for the implementation.

A multi-level governance setting is strongly required. In multi-level governance, different levels of government are mutually dependent on each other (GIZ, 2018). While addressing adaptation, national governments rely on regional and local governments to help implement national climate strategies. Conversely, local and regional governments are affected by the legal, institutional and financial instruments and frameworks put in place by higher levels of governance, which may support or hinder local climate action. Implementing adaptation across levels of governance coherently and effectively requires adequate mechanisms and arrangements for multilevel coordination and cooperation.

The four regional authorities included in the Northern Adriatic area (Friuli Venezia Giulia, Veneto, Emilia Romagna and Marche Regions) have a primary role. They could be represented by those departments and people who already participate in the Technical Committee responsible for the preparation of the Adriatic MSP Plan. Moreover, to bridge MSP with climate change adaptation planning, other relevant regional institutions and people should be involved, to also include the regional departments for the environment that are responsible for climate change adaptation at the regional level (Table 4).

Specific working groups and operational structures established at the regional level shall be also involved. They should at least include:

- the "Regional Forum for Climate Change" and the "Regional Observatory for Climate Change" established by the Emilia Romagna region[7]
- the "coordination group" established in the Veneto region for the preparation of the regional

[7] https://ambiente.regione.emilia-romagna.it/it/cambiamenti-climatici/gli-strumenti/forum-regionale-cambiamenti-climatici last access April 2024.

adaptation strategy, according to the regional decree DGR n. 705 del 14.06.2022[8].

- The technical working group "Clima FVG"[9], which was established by the Friuli Venezia Giulia Region to provide the regional administration with all updated knowledge and tools to face climate change.

Region	Department	Thematic area	website
Friuli Venezia Giulia	Central Direction for the environment, energy and sustainable development – Geological service	Geology, climate change	https://www.regione.fvg.it/rafvg/cms/RAFVG/ambiente-territorio/geologia/FOGLIA22/
Veneto Region	Environment and ecological transition direction	Environment and territory, climate and adaptation to climate change	https://www.regione.veneto.it/web/ambiente-e-territorio/clima-e-adattamento-ai-cambiamenti-climatici
Emilia Romagna region	General directorate for the environment and territory	Environment, ecological transition and climate change	https://ambiente.regione.emilia-romagna.it/it/cambiamenti-climatici/temi/la-regione-per-il-clima/cambiamenti-climatici
Marche Region	Department of infrastructure, territory and civil protection. Environment and Water Resource Direction	Environment, sustainable development	https://www.regione.marche.it/Entra-in-Regione/Sviluppo-Sostenibile/Piano-Clima

Table 4. List of regional departments responsible for climate change adaptation in the North Adriatic area.

Regional agencies for environmental protection (ARPA) can have an important role as providers of data about regional climate change projections, leading monitoring programs that provide synergies with climate change adaptation and participating in dedicated working groups that provide regional administrations with knowledge basis and tools to face climate change.

At the national level, the Ministry of Infrastructure and Transport should be involved as the MSP national authority, in coordination with the Ministry of the Environment that is also responsible for ICZM and the national climate change adaptation plan.

The goal is to form a core team able to sustain the adaptation process in the long term, with a clear mandate. The core team should be advised by experts from the scientific community, including experts in the field of climate change. It should also collaborate with relevant stakeholders of various maritime sectors and activities expected to be particularly exposed to the effects of climate change (i.e. fisheries, aquaculture, tourism, and environmental protection). Stakeholder engagement for climate change adaptation is not considered as a separate process from the engagement organised in the main MSP process, that should remain a unique integrated process. Nonetheless, the action considers the organisation of specific stakeholder events targeted to address climate change issues (workshops, surveys, training events). Capacity building and awareness-raising initiatives are strongly needed to enable a common understanding of climate change issues and their consequences for the maritime sectors and uses.

Dialogue with stakeholders should be considered as a cross-cutting task for all the following steps of

[8] https://www.regione.veneto.it/web/ambiente-e-territorio/clima-e-adattamento-ai-cambiamenti-climatici; last access April 2024.
[9] https://www.arpa.fvg.it/temi/temi/meteo-e-clima/sezioni-principali/cambiamenti-climatici/gruppo-di-lavoro-clima-fvg/; last access April 2024.

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this action. In particular, it will be especially relevant when exploring risks and vulnerabilities (step 2) and when identifying and assessing adaptation options (step 3), to ensure that the adaptation process responds to the actual needs of stakeholders and is feasible, effective and respectful of social justice.

5.1.2 Collecting and structuring existing information on climate change in the Northern Adriatic Sea

This task addresses the need for setting a common knowledge baseline about climate change hazards and impacts in the Adriatic maritime area, with a focus on issues that are directly relevant to maritime sectors addressed by MSP. This means collecting and organising major sources of information coming from scientific journals, international publications, technical reports, and climate information platforms available at the regional level in the case study area.

The connection of the Adriatic Sea with the whole Mediterranean implies to frame local climate change issues in a wider spatial scale, understanding macro-regional and global scale phenomena. Some insights about climate change in the Northern Adriatic Area are described in Chapter 4. Major sources of information are the IPCC Assessment Reports (the latest release is the 6th Assessment Report, IPCC, 2022) and the First Mediterranean Risk Assessment Report (MedECC, 2020) which provide the most authoritative and complete assessment at the global and Mediterranean level respectively.

For the Adriatic basin, and specifically for the Northern Adriatic basin, a high number of scientific papers are available, with special consideration to the issue of sea level rise and flooding of coastal areas. A recent special issue was released in 2021 addressing Venice flooding and reviewing existing data and projections for the northern Adriatic Sea (Lionello et al., 2021). Less information is available for historic trends and projections of seawater temperature, marine heatwaves and related changes in biogeochemical conditions of the Adriatic marine waters. Regional online platforms with tailored climate projections over land areas are available for the Veneto and Friuli Venezia Giulia regions (Regional climate platform for North-east Italy[10]), for Emilia Romagna (Regional climate observatory of Emilia Romagna region)[11] and the Marche Region[12]. Three recently completed European-funded research projects (AdriAdapt, AdriaClim and Change we Care; Interreg VA Italy-Croatia) provided climate projections functional to the elaboration of regional or local adaptation plans. A specific study on climate change scenarios and impacts for Friuli Venezia Giulia[13] has also been prepared to support the preparation of the regional strategy for climate change adaptation.

The whole available information about the spatial distribution of past trends and future projections as well as impacts on sectors and environmental components should be assessed to identify key climate variables relevant for MSP. Selected information should feed the national portal (https://www.sid.mit.gov.it/) and finally support the climate-proofing of the Italian MSP plans.

[10] https://clima.arpa.veneto.it/; last access April 2024.
[11] https://www.arpae.it/it/temi-ambientali/clima/cosa-fa-arpae-clima; last access April 2024.
[12] https://www.regione.marche.it/Entra-in-Regione/Sviluppo-Sostenibile/Piano-Clima; last access April 2024.
[13] https://www.arpa.fvg.it/temi/temi/meteo-e-clima/pubblicazioni/studio-conoscitivo-dei-cambiamenti-climatici-e-di-alcuni-loro-impatti-in-friuli-venezia-giulia/; last access April 2024.

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Regional climate change projections for the Northern Adriatic Sea

The platform for regional climate projections of the North-East (Veneto and Friuli Venezia Giulia regions, land areas). Scenarios RCP 2.6, RCP 4.5 and RCP 8.5. Anomalies for 2021-2050 and 2071-2100 compared to the reference period 1976-2005. Bias correction of 5 regional models part of EURO-CORDEX initiative.

Friuli Venezia Giulia, 2018. Study of climate change scenarios and their impacts. 5 regional models part of the EURO-CORDEX and MED-CORDEX initiatives, scenarios RCP 2.6 and RCP 8.5 for 2021-2050 and for 2071-2100 compared to the reference period 1976-2005.

Regional climate observatory of Emilia Romagna region, land areas. Scenario RCP 4.5, anomalies for 2021-2050 compared to the reference period 1961-1990. Statistical downscaling of global models.

Marche region climate change adaptation plan (Regione Marche, 2022). Scenario RCP 4.5, anomalies for 2021-2050 compared to the reference period 1991-2020, land areas. Regional projections from AdriaClim project.

AdriaClim project (Interreg VA Italy-Croatia, 2020-2023). Climate downscaling from regional (MED-CORDEX) to subregional (AdriaClim Earth system) scale for the Adriatic basin domain; dynamic downscaling in selected marine pilot areas in front of Friuli Venezia Giulia, Veneto and Emilia Romagna regions.

AdriAdapt Project (Interreg VA Italy-Croatia, 2019-2021). Scenario RCP4.5 and RCP 8.5, anomalies 2021-2040, 2041-2060, 2061-2080, 2081-2100 compared to the reference period 1985-2006. Regional projections (EURO-CORDEX initiative) over the ADRIADAPT domain, which runs along the northern coast of Italy and a great part of the Croatian coast, with statistical downscaling in selected municipalities.

Change We Care Project (Interreg Italy-Croatia, 2019-2021, Deliverable 4.1.1). Kilometre-scale Multi-decadal wave projections and ocean circulation simulations for end-of-century (2070-2099) RCP8.5 scenario in the Adriatic Sea, at the basin scale and with a focus on pilot sites, (including sites located in the Northern Adriatic area). Future storm analysis (waves and storm surges) for 2060-2100 on RCP4.5 and RCP8.5 based on an ocean-atmosphere coupled pseudo-global-warming approach. - Analysis of basin-scale thermohaline properties and variability based on regional climate model CNRM-RCSM4 in the near (2011-2040), middle (2041-2070) and far (2071-2100) future and for RCP2.6, RCP4.5, and RCP8.5 emission scenarios.

5.1.3 Collecting and structuring existing information on climate change adaptation planning in the Northern Adriatic Sea

In order to mainstream adaptation in the Adriatic MSP plan, the information on what interventions are ongoing or scheduled as part of other planning instruments relevant to climate change adaptation should be collected. This allows the creation of consistency and synergy between a climate-proof MSP and pre-existing national, regional or sub-regional planning or programming activities relevant to the Northern-Adriatic area.

The national strategy of adaptation to climate change (2015) and the national plan of adaptation to climate change (2023)[14] provide the overarching documents for institutions to further develop the contents of the plan on their governance scale. The involvement of regional authorities in this task is particularly relevant. Regional and municipal adaptation plans, Sustainable Energy and Climate Action

[14] https://www.mase.gov.it/sites/default/files/PNACC_DOCUMENTO_DI_PIANO.pdf last access April 2024.

Plans (SECAPs), as well as integrated coastal zone management initiatives that incorporate climate change, form the basis of this assessment.

In the Northern Adriatic area, two administrative regions have their regional climate change plan or strategy: Emilia Romagna and Marche, while for Friuli Venezia Giulia and Veneto region preparatory works started.

In the Emilia-Romagna region, the Mitigation and Adaptation Strategy was approved in 2018 and constitutes a common framework for mitigation and adaptation for the regional economic sectors and local administrations. The Strategy identifies measures and actions to cope with current climate variability and future climate changes in all the important sectors of the region, including coastal areas, fisheries and aquaculture.

In the Marche region, the climate change adaptation plan was adopted in 2022, as an outcome of the AdriaClim project and implementing one of the actions recommended by the Regional Strategy for Sustainable Development. The plan analyses the vulnerability to climate change for five key sectors (water resources, ecosystems, agriculture and soil, energy and coastal system) and identifies several adaptation measures, some of which are also relevant for the coastal and maritime area. Major examples include measures and actions for the adaptation of coastal and marine ecosystems, coastal areas, fisheries and aquaculture, and tourism.

In addition to regional planning, the Italian platform for climate change adaptation[15] identifies adaptation plans and strategies in four coastal municipalities of Marche Region (Pesaro, Senigallia, Ancona, Fermo), while SECAPs for coastal municipalities are in place for Trieste (Friuli Venezia Giulia Region), Venice, Adige and Po delta (Veneto Region), Cesena and Ravenna (Emilia Romagna region).

5.2 Assessing climate change risks and vulnerabilities

5.2.1 Identification of scenarios for assessing risks and vulnerability in the Northern Adriatic area

This step addresses the identification of operational scenarios functional to the following analysis of risks and vulnerabilities and to the consequential planning adaptation actions. By scenario we mean an image of the future, developed on the basis of a series of hypotheses for the development of events on which it depends. The scenarios are therefore not configured as a real prediction, but rather as possible alternatives, in which a certain process may evolve in the future. Scenarios represent the most commonly used tool to analyse possible variations of climate forcing and their impacts.
The IPCC's sixth assessment report identifies 5 scenarios, defined on the basis of different possible evolutions of the socio-economic system. The scenarios are identified by a double acronym which in the first part refers to the "Shared socioeconomic pathway" (SSP) and in the second part to the radiative forcing (W/m^2) reached by 2100 (e.g. SSP5-RCP 8.5). SSPs consist of a narrative that outlines the general characteristics of a possible global future. Each of the five IPCC scenarios therefore combines a socioeconomic development trajectory with a greenhouse gas emissions scenario (Riahi et al., 2017), thus highlighting the link between socioeconomic choices and climate change in the 21st century.

To perform a vulnerability analysis of the Northern Adriatic Area to climate change, and to plan adaptation solutions relevant for MSP, 2 or 3 "storyline" scenarios and related climate projections should be deployed, based on low, medium and high emission IPCC scenarios. Storyline scenarios refer

[15] Piattaforma nazionale Adattamento Cambiamenti Climatici: https://climadat.isprambiente.it/; last access January 2024

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to a narrative description of a scenario including its main characteristics, relationships between driving forces and how these factors evolve (IPCC, 2022) The future evolution of main climate variables over different planning units of the Northern Adriatic basin could be investigated capitalising on and harmonising available regional projections (Chapter 4).

Model projections of climate variables in scenario-based simulation commonly refer to mid-century (2050) or the end of the century (2100) with thirty-year average values. For the scopes of MSP, 2050 is the most relevant horizon time, since it is closer to the revision cycle of the maritime spatial plans and to the timeframes both used in adaptation plans and sectoral development plans. The evolution of climate variables by 2100 should also be considered to get a long-term vision of climate change challenges, adding a future-looking perspective to MSP.

5.2.2 Analysis of areas and sectors particularly at risk

The concept of climate change risk is the result of the interaction of *hazard* (climate-related physical events, trends or their physical impacts), *exposure* (presence of people, livelihoods, species or ecosystems, various assets and functions that could be adversely affected) and *vulnerability* (propensity or predisposition to be adversely affected, depending on the sensitivity to harm and to the adaptation capacity).

Impact chains (GIZ and EURAC, 2017; Zebisch et al., 2022) are useful tools to delineate conceptual models for climate change risk analysis. They are cause-effect chains that include all major factors and processes leading to specific climate risks in a specific context (e.g., regional and/or sectoral). Impact chains are usually developed in a participatory manner (Zebisch et al., 2022) together with stakeholders and experts to create a commonly agreed picture of root causes for climate risks in a specific context. This allows the integration of scientific data coming from research and modelling activities with data and perceptions coming from stakeholders directly affected by climate change (e.g. fisheries associations, tourism operators, managers of protected areas).

The figures below illustrate preliminary impact chains that apply to relevant sectors of the Adriatic MSP (fisheries, aquaculture, coastal and maritime tourism, environmental protection), built upon the information presented in Chapter 4.

To perform the vulnerability analysis, the exposure and vulnerability elements delineated in the impact chains need to be investigated, using quantitative or qualitative data, depending on the availability of information. This should help compare the different planning units of the area (A1, A2, A3, A4, and A7, Figure 2) and will ultimately support the definition of areas and sectors particularly at risk from climate change. A combined approach for the analysis that merges a top-down and a bottom-up approach should be followed. This means that information on climate risks and vulnerability should be compiled by both gathering information from the scientific literature/research projects (i.e. what are the impacts that science identifies) and by collecting stakeholders' perceptions (i.e. what are the impacts perceived/experienced by stakeholders of different sectors).

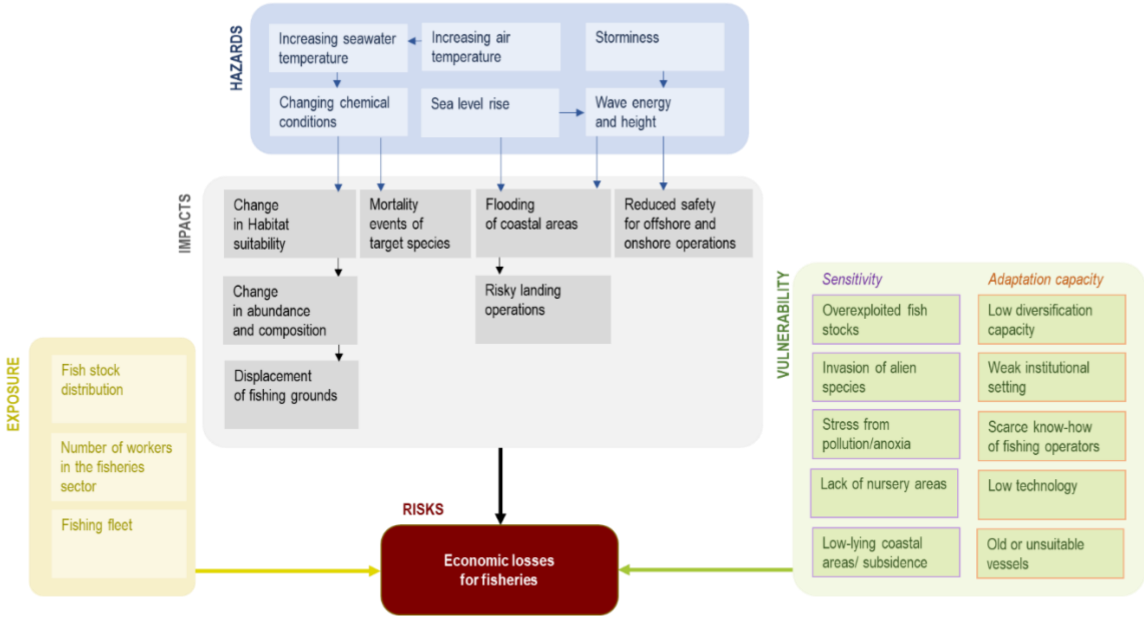

Figure 12. Impact chain for assessing risks in the fisheries sector. Source: own elaboration based on the impact chain model of Zebisch et al., 2022.

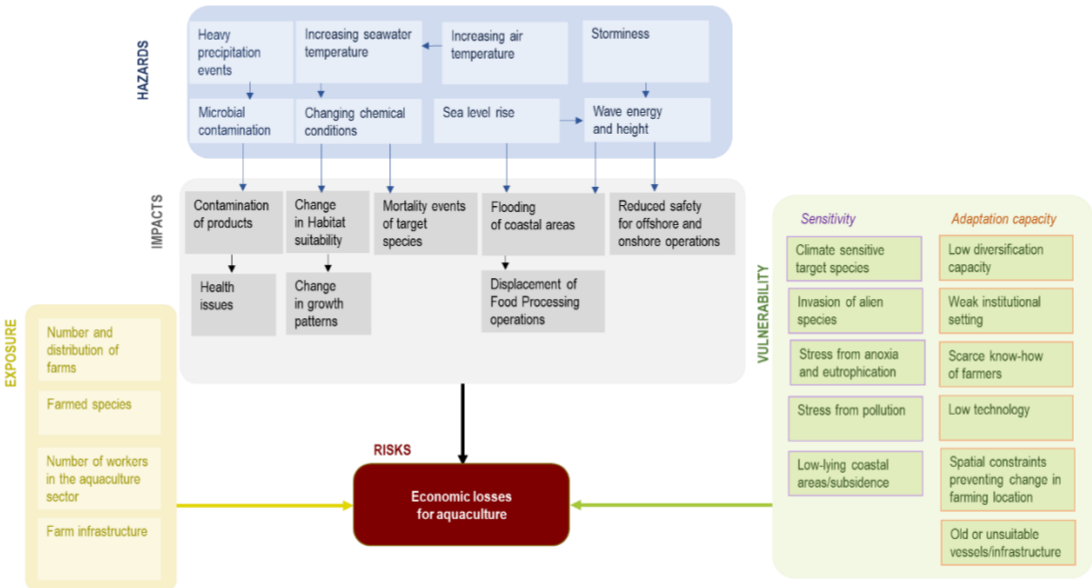

Figure 13. Impact chain for assessing risks in the aquaculture sector. Source: own elaboration based on the impact chain model of Zebisch et al., 2022.

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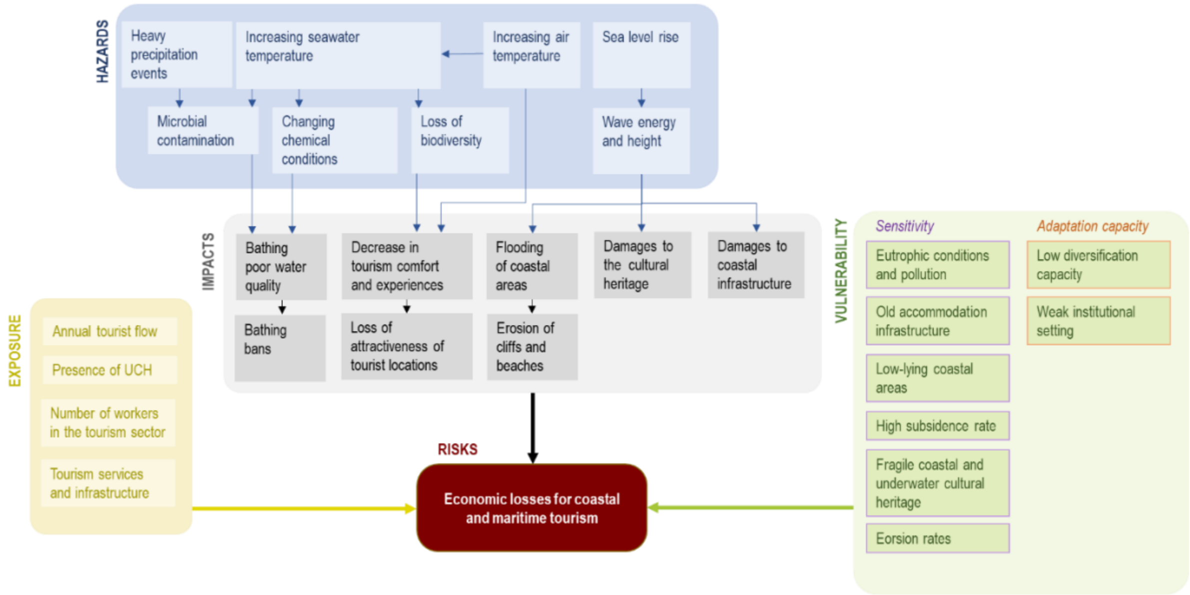

Figure 14. Impact chain for assessing risks in the tourism sector. Source: own elaboration based on the impact chain model of Zebisch et al., 2022.

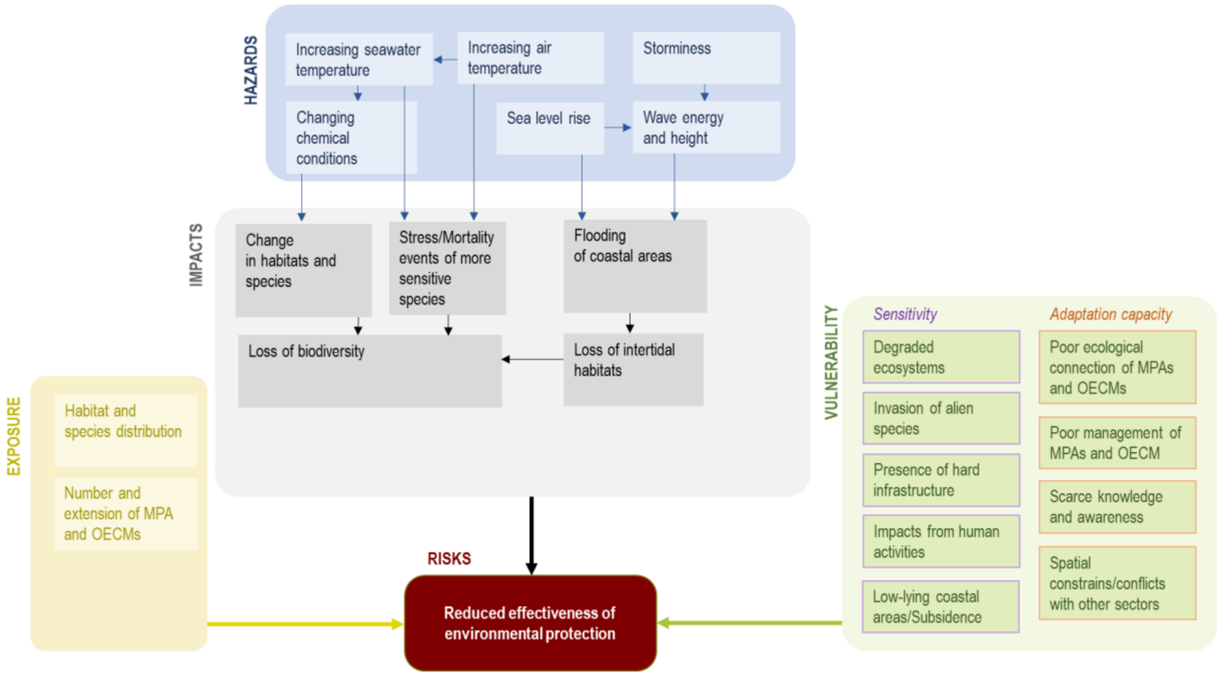

Figure 15. Impact chain for assessing risks for environmental protection. Source: own elaboration based on the impact chain model of Zebisch et al., 2022.

5.3 Identifying and assessing adaptation options

Adaptation options are measures and strategies available and appropriate for addressing climate change (IPCC AR6 glossary). This task addresses the identification and assessment of adaptation options that can be potentially incorporated into the Adriatic MSP plan.

The first step is to select a preliminary list of possible adaptation options relevant to MSP in the Northern Adriatic Sea. This selection should be based on national and regional plans that envision the realisation of adaptation measures in the coastal and marine area and should be informed by existing acknowledged catalogues of adaptation options (see the following box). The preliminary list will identify those options that:

- match the MSP sectors and activities (including environmental protection) of the Northern Adriatic area;
- are MSP-relevant. Adaptation options that can be potentially considered should generally have a spatial dimension or be related to regulations and governance aspects that can enable the MSP implementation from a climate change perspective.

The second step is to assess the most appropriate options that could be incorporated into the Adriatic MSP plan. This activity should be guided by clear criteria:

- Avoidance of maladaptation: adaptation options implemented to address the vulnerability of one area or sector must not increase the vulnerability of other areas and sectors or further increase emissions of greenhouse gasses. Adaptation solutions should not create disproportions among different social groups, and create conflict with environmental and sustainability policy goals;
- Nature-based solutions approaches are largely preferred, to be in line with the objectives of the EU adaptation strategy and the EU Green Deal;
- Maximisation of synergies with measures already envisaged by existing adaptation plans and processes at the national and regional levels;
- Maximisation of synergies with other climate change-related measures included in the current version of the MSP plan;
- Maximisation of synergies with climate change mitigation objectives;
- Multi-scalar approach. This principle is at the foundation of the Italian MSP that aims at implementing decision-making and spatial planning at multiple and nested scales (Ramieri et al., 2024). The adaptation options should be planned at the lowest relevant spatial and governance scale but its integration with higher levels of governance should also be carefully considered. A multi-scalar approach will ultimately favour replicability and upscaling of adaptation options;
- Feasibility versus effectiveness. Feasibility includes economic, technological, institutional, environmental and societal factors, while effectiveness assesses the capacity of the option to reduce climate change risks;
- Consideration for social justice and fair transition, to ensure that benefits and burdens of adaptation are distributed among different groups according to equity principles and considering the impacts for future generations;

The whole activity needs to be done by the previously established core team, in strict collaboration with the stakeholders of the affected sectors and the selected experts in the field of climate change.

Box. Repositories of information supporting the identification and assessment of adaptation options

At the global level, inspiration for adaptation options can be found in the IPCC reports (working Group II), with particular reference to chapter 17 of the AR6 report (IPCC, 2022)) which includes a list of 24 adaptation options organised per "key representative risks". At the European level, information on adaptation options can be found in the Climate-ADAPT Platform operated by the European Commission and the European Environment Agency. The Climate-ADAPT catalogue[16] is composed of 58 options categorised according to the "Key type measures" (KTM), a system used to report climate adaptation actions in the EEA countries under the Energy Union Governance Regulation (Regulation (EU) 2018/1999).

At the Mediterranean scale, the MSP workspace (PAP/RAC-UNEP)[17] offers a learning environment for integrating climate change actions into the MSP. At the Adriatic scale, the AdriAdapt platform[18], developed within the Interreg Italy- Croatia ADRIADAPT Project, includes societal options, green options and grey options for adapting to climate change, tailored to the Adriatic regions.

Some examples of adaptation options that could be considered to address the previously described climate change risks in the framework of the MSP process are described in the following text.

Diversification of fisheries and aquaculture

Livelihood diversification in communities dependent on marine and coastal ecosystems reduces climate risks and confers flexibility to individuals, which is key to adaptive capacity (IPCC AR6 report, Chapter 2). Diversification strategies include the shift towards alternative species or – in the case of aquaculture - new genetic strains, as well as management practices more adapted to changed conditions (Climate-ADAPT[19]*)*. In an MSP context, diversification may be supported by modelling future temporal and spatial dynamics of commercial species shift due to climate change, and by identifying new areas that might become important for fisheries and aquaculture in the future. The identification of new areas should be supported by a robust spatial analysis of conflicts among different sea uses and the quantification of cumulative impacts of human activities on the same space. The MUC (Maritime Use Conflicts) and CEA (Cumulative Effects Assessment) tools (part of the Tools4MSP suite[20]) are examples of tools used in various projects focusing on MSP in the Adriatic (e.g. Portodimare funded by Adriatic-Ionian Interreg). The adaptation process can also include initiatives of business diversification (temporary or permanent) outside the sector, such as the development of "pesca-tourism" and "aquaculture-tourism" initiatives that can provide complementary sources of income for operators. In any case, diversification must respect the principles of the EU common fisheries policy, not increase the overall pressures on fish stocks and contribute to enhancing the sustainability of these sectors.

Developing marine and coastal ecotourism

Ecotourism, is a type of tourism that supports nature conservation, sustains the well-being of the local people, and involves interpretation and education (International ecotourism society website[21]).

[16] https://climate-adapt.eea.europa.eu/en/knowledge/adaptation-information/adaptation-options; last access January 2024
[17] https://msp.iczmplatform.org/;last access January 2024
[18] https://adriadapt.eu/; last access January 2024
[19] https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/diversification-of-fisheries-and-aquaculture-products-and-systems; last access January 2024
[20] http://data.adriplan.eu/tools4msp/; last access January 2024
[21] https://ecotourism.org/what-is-ecotourism/; last access January 2024

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Ecotourism can be part of the adaptation process to climate change, as it provides support to local coastal communities affected by diverse impacts of climate change and at the same time helps to preserve natural habitats. Maritime and coastal ecotourism can include a wide range of activities such as "pescatourism", "aquaculture-tourism", regulated snorkelling/diving activities to underwater cultural heritage sites or environmental sites, trips to discover the coastal landscape, etc. Ecotourism may also include activities to reduce peak tourism flows concentrated in a single season, by promoting alternative activities distributed in all seasons. However, this must be carefully planned and monitored, so not to create the opposite effect of increasing tourism pressure on vulnerable ecosystems. The effectiveness of ecotourism for adaptation depends on the implementation of adequate capacity-building initiatives, citizen science and awareness-raising projects. Unintended consequences of ecotourism, such as harmful ecological impacts on species and habitats, can be minimized by relying on evidence-based management of associated activities (IPCC, 2022). This aspect shall be reflected in MSP plans, by allocating areas where ecotourism and environmental protection can coexist and even by limiting areas where the most impacting recreational activities (such as leisure boating and uncontrolled anchoring) are allowed.

Optimisation of aquaculture zoning and siting

There is a growing interest in aquaculture as a way to reduce the impacts of wild species capture, but also to favour ecosystem restoration and provide ecosystem services (restorative aquaculture). Examples include siting farms (Alleway et al., 2023) to enhance nutrient removal and improve water quality, to create new habitats as shelter areas for fauna, to attenuate wave energy in coastal areas, and to support the conservation of native species.

Whenever siting farms is informed by climate change considerations (risk-based zoning and siting) of aquaculture, this can also help avoid areas particularly vulnerable to climate risks and select the most suitable areas for the cultured species, considering both the current state and the challenges posed by climate change in the medium-long term. The overall process allows for minimizing possible economic losses that could derive from choices that do not take all risks and concerns into account (Climate-ADAPT[22]) while maximising environmental benefits. To define allocated zones for aquaculture (AZA, zoning step) and specific locations suitable for new farming activities (siting step), a complete analysis of the main threats to a successful production should be performed. The approach is encouraged by FAO (FAO, 2018; FAO & World Bank, 2017). This adaptation option should favour the adoption of the principles of restorative aquaculture and the implementation of low trophic aquaculture (for example extensive mussel and seaweed farming) and integrated systems (IMTA) to minimize environmental impacts.

Early warning systems supported by monitoring, modelling and forecasting systems can be also part of the adaptation option. These systems can alert farmers in case of adverse weather or environmental conditions that may trigger harmful algal blooms and microbiological contamination.

Establishment of MPAs, OECMs, and climate refugia

Marine Protected Areas (MPAs) and Other Effective Area-based Conservation Measures (OECMs) include ecosystems of high ecological value, where different degrees of environmental protection are put in place. In strictly protected areas (included in MPAs), all human activities are prohibited except for scientific research. In several other cases (e.g. specific zones of MPAs and Natura 2000 sites) human presence is allowed, including, for example, regulated tourism, recreational activities, artisanal

[22] https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/risk-based-zoning-and-siting-for-marine-aquaculture; last access January 2024

fisheries and some typologies of aquaculture (AdriAdapt Platform[23]). The establishment of MPAs and recognition of OECMs can be part of the adaptation process since they help preserve healthy ecosystems with enhanced resilience to climate change. Whenever these areas include climate *refugia* (areas that are supposed to remain relatively preserved from the effects of climate change over time, with a crucial role in safeguarding biodiversity), their relevance for adaptation is particularly high. MSP can implement this option by contributing to allocating new and interconnected marine areas to environmental protection, with strong consideration for preserving climate *refugia* and for creating networks of areas that can function as corridors for mobile species.

Environmental restoration of coastal and marine ecosystems

This adaptation option embraces different possible interventions aimed at restoring coastal and marine ecosystems that play a relevant role in buffering climate change impacts. These systems include coastal lagoons, saltmarshes, seagrass meadows and coralligenous, which can attenuate wave energy, slow down marine currents, and favour sediment entrapping, finally reducing the risk of erosion and flooding. They provide coastal communities with a wide range of ecosystem services such as improving water quality and sustaining coastal fisheries, since they host a high variety of species. *Posidonia oceanica* has particular relevance among seagrass species (although it is poorly present in the Mediterranean), and its role in biodiversity is well acknowledged and documented, while other seagrass species (*Zoostera* spp and *Cymodocea* spp) are also relevant, especially for the Northern Adriatic Sea. Important synergies with climate change mitigation exist: these ecosystems are often referred as "blue carbon ecosystems", for the ability of coastal and submerged vegetation to sequester carbon through their biomass. MSP can implement this option by limiting certain uses that are detrimental to coastal and marine ecosystems and by prioritising environmental protection activities in the most vulnerable areas.

Integration of climate change adaptation in ICZM

Integrated Coastal Zone Management (ICZM) is an acknowledged process to deal with current and long-term coastal challenges, including climate change. It is expected to promote a flexible management of coastal zones, by ensuring proper monitoring of the plan implementation, its periodic revision, as well as the refinement and improvement of outcomes according to the learning-by-doing approach. Developing climate-informed ICZM and integrating their results into MSP (especially while addressing land-sea interactions) is a possible adaptation option to be considered.

Beach and shoreface nourishment

Sand nourishment is the artificial placement of sand on an eroded shore to compensate for erosion, often aggravated by sea level rise induced by climate change. The adaptation option may differ according to the source of sediments used for nourishment (inland or nearshore sources, offshore marine sands) and the used technique (beach, backshore and shoreface nourishment). Though this option is commonly referred to as a green measure, it is not completely deprived of impacts and it does not stop the erosion process. For this reason, it needs to be carefully planned, and implemented in the short-medium term, especially to preserve economic activities, infrastructure, and assets, until a more comprehensive and long-term strategy aimed at restoring the natural process of land-sea sediment transport and dispersion. In this regard, it should be ideally incorporated as a temporary measure in long-term ICZM plans and combined with other green measures both on land and at sea such as the naturalisation of rivers, dune restoration and strengthening and restoration of coastal and marine ecosystems.

[23] https://adriadapt.eu/adaptation-options/marine-protected-areas-and-other-effective-area-based-conservation-measures/; last access January 2024

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Increasing the resilience of seaports

Ports are exposed to the risk of climate change, considering their location in coastal zones, low-lying areas and deltas. Ports are particularly affected by sea level rise, storm surges, waves and winds. Though seaports are normally designed to be resilient to several pressures, climate change requires the implementation of additional measures. Both societal measures (improved operational management, early warning systems, training of operators, emergency procedures) and structural measures (infrastructure elevation, improved design, new materials, dykes, seawalls, breakwaters) are possible. For hard engineering works, possible environmental impacts (increased erosion in nearby areas, habitat disruption) must be assessed. Relocation of seaports should be considered only when the seaport is significantly at risk of inundation, being a very expensive solution.

Capacity-building and awareness-raising initiatives

Capacity building for climate change adaptation addresses specific target groups to enable the improvement of their skills, and the use of tools, equipment or other resources that make them better prepared for climate change challenges. Awareness raising encompasses actions that generally involve citizens or specific stakeholders to encourage individual and societal behavioural changes to address the altered conditions under climate change and to promote adaptation measures. Both initiatives are cross-cutting and generally complement the implementation of any adaptation option. They also frame within the general stakeholder engagement process of MSP, which requires the organisation of specific events of training and awareness raising to build a common understanding of climate change processes and their relationship with the marine environment and maritime sectors.

All the above-described adaptation options are consistent and offer synergies with some measures already included in the Adriatic MSP plan (see Chapter 3). The following table presents the list of adaptation options, the main MSP-affected sectors and the corresponding measures included in the MSP plan for the Adriatic Sea.

Adaptation option	Main sector	Other sectors	Correspondent measures included in the Adriatic MSP plan
Diversification of fisheries and aquaculture	Fisheries Aquaculture	Tourism Environmental protection	(A/2)_MIS|13 and (A/2)_MIS|14. Actions to support small-scale fisheries and their sustainability.
Developing marine and coastal ecotourism	Tourism	Environmental protection Fisheries Aquaculture	(A/2)_MIS|13 and (A/2)_MIS|14. Actions to support small-scale fisheries and their sustainability (note: possible connections with pesca-tourism)
Optimisation of aquaculture zoning and siting	Aquaculture		(A/2)_MIS|16. Adopt a provision from the Regional Council to define the AZA (Allocated Zones for Aquaculture) in the sea, as macro-areas of eligibility for the issuing of concessions for aquaculture purposes. (A/3)_MIS|1. Establish a working group aimed at regulating coastal defence, aquaculture and fishery in some coastal areas where there are needs for sand collection or disposal for coastal defence interventions and protection of nursery areas

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Adaptation option	Main sector	Other sectors	Correspondent measures included in the Adriatic MSP plan
Establishment of MPAs, OECMs, and climate refugia	Environmental protection	Tourism	NAZ_MIS|15. Establish a "MSP-MSFD-Biodiversity Strategy-Fishery policy" working group linked to the activities of the Technical Committee for MSP. This group aims to identify the priority areas for the conservation of the environment and/or marine resources to expand the network of MPAs and/or sites of the Natura 2000 Network, in line with the provisions of the MSFD Directives, and to advance in the operationalisation of OECMs (A/1)_MIS|9. Mapping the distribution and assessing the quality of pre-coralligenous formations and seagrass meadows, to monitor their state of conservation, even outside protected areas. (A/3)_MIS|6. Expand the SCI areas at sea and monitor the implementation of conservation measures of the Site of Community Interest (SCI) Northern Adriatic - Emilia-Romagna (IT4060018) and of the Special Area of Conservation (SAC) Wreck of the Paguro platform (IT4070026).
Environmental restoration of coastal and marine ecosystems	Environmental protection		(A/1)_MIS|9. Mapping the distribution and assessing the quality of pre-coralligenous formations and seagrass meadows, to monitor their state of conservation, even outside protected areas.
Integration of climate change adaptation in ICZM	Coastal defence	Tourism	NAZ_MIS|71. Promote an improved coherence among other planning instruments or initiatives, such as existing ICZM/coastal strategies and plans, NAZ_MIS|28. Integrate the data and information available within the national database on illegal buildings, to develop a study on the extent of infrastructure in the 300 metres coastal strip NAZ_MIS|70. Reactivate the pre-existing "National Coastal Erosion Table" to address Integrated Coastal Zone Management in a coordinated way at the national level. (A/2)_MIS|17. Update the document "Integrated Management of the Coastal Zone - Study and monitoring for the definition of coastal protection interventions from erosion in the Veneto Region - Guidelines" approved with DGR 898 of 14 June 2016;

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Adaptation option	Main sector	Other sectors	Correspondent measures included in the Adriatic MSP plan
Beach and shoreface nourishment	Coastal defence	Tourism	NAZ_MIS|72. complete the mapping and the assessment of the quality and the quantification of the volumes of underwater sand deposits to properly plan their use. (A/1)_MIS|16. Mapping and characterization of relict marine sand deposits for the creation of "functional beaches" for the safety of the coastal territories and the conservation of the specificities of the coast (A/2)_MIS|17. Allocate funds for coastal defence interventions (restoring coastal dune ecosystem and nourishment) (A/3)_MIS|1. Establish a working group aimed at regulating coastal defence, aquaculture and fishery in some coastal areas where there are needs for sand collection or disposal for coastal defence interventions and protection of nursery areas. (A/3)_MIS|2. Improve knowledge of offshore sand deposits which, for the Emilia-Romagna Region, represent the main external source of sand supply and strengthen data management tools (regional geoDB in_SAnd) following the provisions of the action C1.4 of the GIDAC regional strategy (Integrated management for the defence and adaptation of the coast to climate change.
Increasing the resilience of seaports	Maritime transport and ports	Coastal defence	NAZ_MIS|59. Monitor the updating and revision of port master plans and other plans directly or indirectly related to port activities (including those focused on environmental issues) to ensure the transfer of necessary adjustments into MSP Plans. *(adaptation measures to make ports more resilient to climate change may be integrated into the revision of planning port regulations)*

Table 5. Potential adaptation options to be considered in the Northern Adriatic area and their link to measures already included in the Adriatic MSP plan.

5.4 Implementing, monitoring and evaluating adaptation

The final step of the action is the implementation of the selected adaptation measures – as part of the implementation process of the whole MSP plan - and the organisation of a scheme of monitoring and evaluation to track the adaptation progress and outcomes, again part of the wider monitoring mechanism set in place for the entire MSP process.

To favour the implementation of measures and their tracking in national reporting obligations towards the European Commission, the selected adaptation measures might be categorised according to the system of Key Type Measures (KTM). The concept of KTMs was initially developed in 2012 for the

Water Framework Directive (WFD) and then also applied to the Flood Directive. In 2021, the KTM approach for adaptation was applied for the first time, voluntarily, by the Member States in the national adaptation reporting under the Regulation on the Governance of the Energy Union and Climate Action in 2021 (Leitner et al., 2021), see Table 6. The use of this type of categorisation to track the implementation of adaptation solutions within the overall implementation of the MSP plan can be effective in further mainstream climate change adaptation policies into maritime spatial planning.

KTM	Sub-KTM[17]	Specifications
A: Governance and Institutional	**A1: Policy instruments**	• Creation / revision of policies • Creation / revision of (implementing) regulations
	A2: Management and planning	• Mainstreaming adaptation into other sectors • Creation / revision of technical rules, codes and standards
	A3: Coordination, cooperation and networks	• Creation / revision of ministerial coordination formats • Creation / revision of stakeholder networks
B: Economic and Finance	**B1: Financing and incentive instruments**	• Creation / revision of incentive mechanisms • Creation / revision of funding schemes
	B2: Insurance and risk sharing instruments	• Creation / revision of insurance schemes and products • Creation / revision of contingency funds for emergencies
C: Physical and Technological	**C1: Grey options**	• New physical infrastructure(s) • Rehabilitation, upgrade and / or replacement of physical infrastructure(s)
	C2: Technological options	• Early warning systems • Hazard / risk mapping • Service / process applications
D: Nature Based Solutions and Ecosystem-based Approaches	**D1: Green options**	• Creation of new / improvement of exiting green infrastructure • Natural and / or semi-natural land-use
	D2: Blue options	• Creation of new / improvement of existing blue infrastructure • Natural and / or semi-natural water and marine areas management
E: Knowledge and Behavioural change	**E1: Information and awareness raising**	• Research and innovation • Communication and dissemination • Decision support tools and databases
	E2: Capacity building, empowering and lifestyle practices[18]	• Identification and sharing of good practices • Training and knowledge transfer • Reporting on lifestyle practices and behaviours

Table 6. Key type measures for adaptation. Source: Leitner et al., 2021.

To enable the implementation of solutions over time according to different levels of climate risk, an increasingly used approach to organise and track the progressive implementation of the adaptation solutions is the development of adaptation pathways (Buurman & Babovic, 2016; Werners et al., 2021). They are alternative sequences of actions (adaptation measures) which can be implemented progressively, depending on future dynamics. When a critical threshold is reached (tipping point), climate change imposes to change direction and consider alternative strategies more effective to counteract the new risk level. Charts of adaptation pathways can also be a tool used to engage stakeholders in the decision-making process, by offering a visual representation that can support communication (Figure 16 and Figure 17).

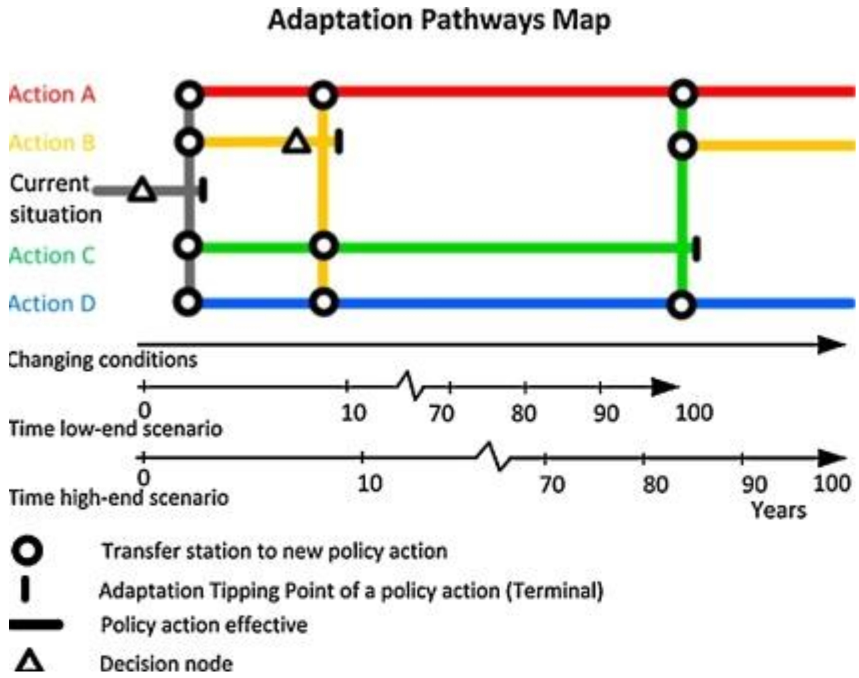

Figure 16. The general conceptual model of adaptation pathways. Source: Zandvoort et al., 2017.

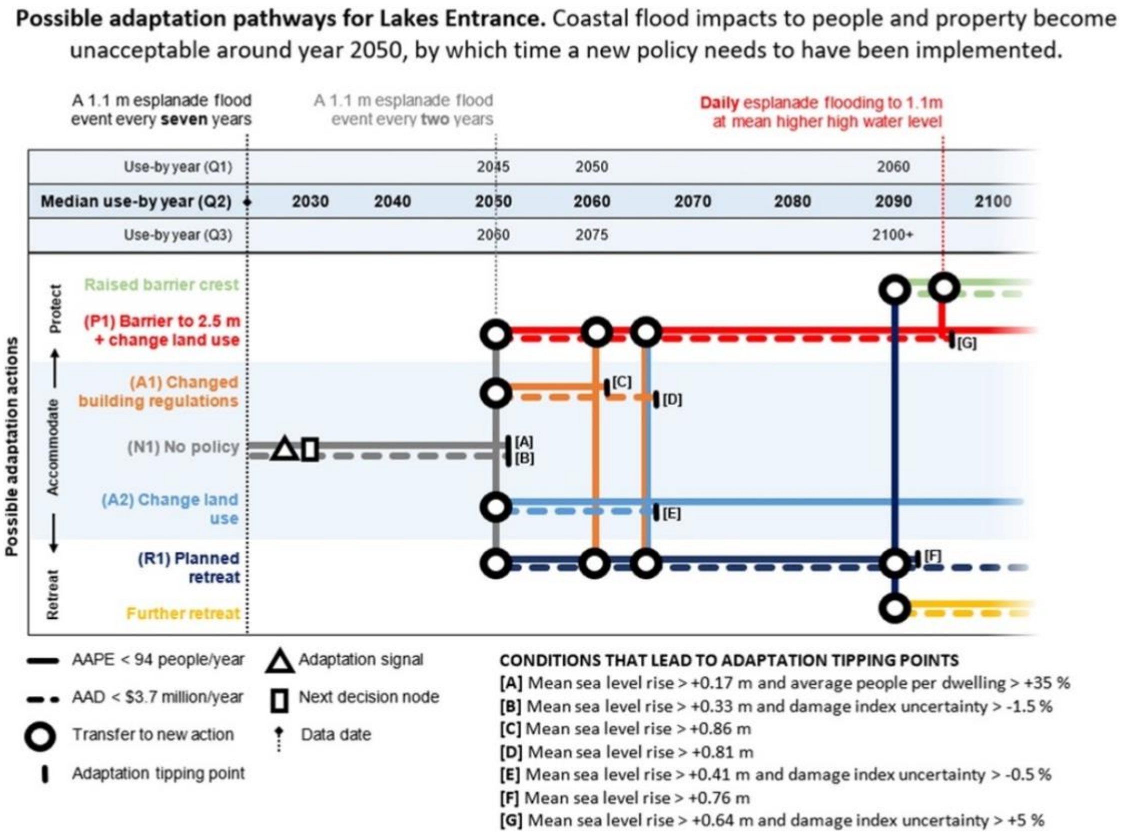

Figure 17. Example of an adaptation pathway for the management of coastal development. Source: Ramm et al., 2018.

For monitoring the adaptation progress over time, the definition of a set of indicators is a crucial step. However, though monitoring and evaluation of adaptation progress is key for climate risk management, it is still in an early stage in many countries (IPCC, 2022) and insufficiently used to assess the long-term effects of adaptation interventions. Indicators should be able to both track the progress in the implementation of the selected adaptation options and their outcomes in terms of adaptation (risk reduction) and also in delivering co-benefits (for the environment, the society and the economy), to minimise the risk of maladaptation.

The monitoring of the adaptation measures should not be implemented as a separate initiative from the main monitoring scheme envisaged by the national MSP plan. This should be instead fully mainstreamed in the main sequence of actions described in the MSP plan:

- Step 1: Selection of the strategic objectives and specific objectives to be tracked
- Step 2: Identification of the actors with responsibility for monitoring
- Step 3: Identification of indicators (environmental/socio-economic/governance)
- Step 3: Identification of pre-existing monitoring programs
- Step 4: Identification of data sources
- Step 5 Development of the monitoring plan

The first entry point for monitoring the implementation of adaptation actions is Step 1 of this process, where relevant strategic objectives for adaptation are selected. As detailed in Chapter 3 and Table 1 of this document, relevant crosscutting strategic objectives for adaptation refer to the topic of sustainable development (OS_S) and environmental protection (OS_N). The sectoral strategic objectives of coastal defence (OS_DC), landscape and cultural heritage (OS_PPC), fisheries (OS_F) and aquaculture (OS_A) are also relevant.

Once the relevant objectives have been defined, the actors with responsibility for monitoring should be defined. In this step, the relevant authorities introduced in previous sessions need to be involved.

For step 3, the definition of indicators should be done, linking with the indicators already identified in the MSP plans. The choice of indicators is designed to be integrated with the overall framework of indicators included in the national MSP plan. Some indicators could be adapted to specifically consider the specific issue of climate change, while synergies with other ongoing monitoring frameworks (EU Marine Strategy Directive, EU Flood directive) should be maximised.

In Table 7, a preliminary screening of indicators potentially relevant for adaptation is presented. New or adjusted indicators can be also proposed to specifically track the progress of specific adaptation options. For example, indicators 2.7 “Percentage of marine waters with marine protected areas” and 2.8 “Number of marine protected areas that are managed properly, ecologically representative and functionally interconnected”, could be adapted to incorporate the percentage or the number of marine protected areas with management plans that incorporate climate change adaptation strategies.

Strategic objective	Indicator
OS_S sustainable development	Bathing water quality index
	Percentage of coastal areas suitable for bathing
	Surface of marine protected areas
	New surface areas (%) proposed for establishing new marine protected areas
	Number of new proposals for the establishment of Fisheries restricted areas (FRA)
	Number of interventions for reducing the environmental impacts of aquaculture

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Strategic objective	Indicator
	Percentage of overexploited fish stocks
OS_N Environmental protection	Funds for the establishment of marine and coastal protected areas
	Percentage of marine waters with marine protected areas
	Number of marine protected areas that are managed properly, ecologically representative and functionally interconnected
	Update of management plans of marine protected areas.
OS_PPC landscape and cultural heritage	Illegal building rate in coastal areas
	Presence of plans for coastal areas
OS_P Fisheries	Percentage of marine waters where Biological Protection Zones and Fisheries Restricted Areas are established
	Number of Biological Protection Zones and Fisheries restricted areas
	Number of jobs for small-scale fisheries and “pescatourism”
	New areas for aquaculture sites
	Number of projects for defining AZA according to the national guidelines
OSS_D coastal defence	Beaches suffering from erosion
	Intervention of sand nourishment
	Coverage of urbanised soil
	Cost of nourishment interventions
	Percentage of protected areas along the coast
	Population living in coastal areas
	Change in the coastline
	Length of the coastline with coastal defence measures
	Coastal zone subsidence
OS_T Tourism	Number of tourists overnight stays in structures that participate in climate change mitigation programs and that propose activities and strategies to support sustainable tourism
	Percentage of tourist businesses/facilities in destinations that use a voluntary certification/brand for environmental measures/sustainability and/or social corporate
	Percentage of tourism businesses that participate in climate change mitigation programs, such as CO_2 offsetting, low energy consumption systems, etc., and that implement "adaptation" responses and actions
	Percentage of local businesses in the tourism sector that actively support the protection, conservation and management of biodiversity and local landscapes
	Percentage of accommodation facilities and tourist attraction infrastructures located in "vulnerable areas"

Table 7. A subset of indicators, per strategic objective, relevant for climate change adaptation.

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6. Concluding remarks

The action designed in this report aims to support the process of climate-proofing the MSP plan in the Northern Adriatic area. Consistency and continuity between adaptation planning and MSP are at the foundation of the designed action. The action is therefore framed within a portfolio of objectives and measures already envisioned by the MSP plan that includes explicit or implicit elements of connection with climate change adaptation.

The action is designed according to the typical policy cycle of adaptation that starts from setting the ground for adaptation and then includes the successive steps of assessing climate change risks and vulnerability, identifying and assessing possible adaptation options, implementing measures, and finally monitoring and evaluating the adaptation outcomes.

The action is tailored to the Northern Adriatic area, where a preliminary assessment of climate change impacts on marine sectors has been proposed, based on literature. Nonetheless, the action can be easily scaled up to cover the whole Adriatic basin and the two other maritime areas enclosed in the national MSP plan (Tyrrhenian and Ionian-central Mediterranean).

The actual availability of information about regional climate change projections and elements of vulnerability and exposure may prevent detailed and quantitative analysis of climate change risks for specific areas and sectors. Therefore, the action is designed to be flexible, also envisioning the possibility to use qualitative assessments or proxy data, whenever quantitative information is not available. Perceived impacts from stakeholders of different sectors, directly experiencing the effects of climate change are considered an integral part of the knowledge basis needed to build the adaptation process. Flexibility is also a necessary condition to deal with the uncertainties of climate change. Knowledge on climate change is rapidly evolving and this can lead to the raising of future unexpected risks that require different prioritization of adaptation options or even different solutions.

The action is designed to work with a long-term perspective since climate change projections usually have a timeframe of 50 to 100 years. This long-term perspective needs to be integrated into the timeframe of the MSP plan that normally works with a shorter time frame (revision cycle of 10 years) but that at the same time often accommodates longer-term vision.

Limited research and operationalisation of adaptation measures for several maritime sectors (fisheries and aquaculture in particular) may limit the implementation of the action. For example, several research studies investigated the possible responses of commercial fish species to climate change based on scenarios and modelling; however, practical solutions to address this issue often remain theoretical and lack examples of operational implementation. Such limited operationalisation represents an important challenge.

Another challenge is related to the need to create a multi-level and integrated governance structure able to link MSP with climate change policies. The establishment of the core team to follow the adaptation process within the MSP is considered a key step.

Despite challenges, the expected benefits of long-term planning of the sea space from a climate change perspective are manifold. The action is expected to contribute to minimising economic losses due to short-sight development choices that do not properly consider climate change, minimise possible new conflicts emerging from changed distribution of uses and minimise environmental impacts on the marine ecosystem that can impair ecosystem services.

Well-tracked adaptation outcomes have the potential to guide possible future investment and unfold

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new funding possibilities. Monitoring, evaluation and progressive adjustment of the whole process is therefore a crucial step to assess the effectiveness of the implemented solutions in terms of adaptation and to assess environmental and socio-economic co-benefits.

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