Climate and environmental coastal risks in the Mediterranean

by MedECC
Mediterranean Experts on Climate and environmental Change

Union for the Mediterranean
Union pour la Méditerranée
الاتحاد من أجل المتوسط
UN environment programme
Mediterranean Action Plan
Barcelona Convention
Plan Bleu

MEDITERRANEAN EXPERTS ON CLIMATE AND ENVIRONMENTAL CHANGE

ISBN: 978-2-493662-02-6 doi: 10.5281/zenodo.13754020

Disclaimer

The content and views expressed in this document are purely those of the authors and may not, in any circumstances, be interpreted as stating an official position of the supporting institutions. Neither the supporting institutions nor any person acting on their behalf may be held responsible for the use, which may be made of the information contained therein. The designations employed and the presentation of the material do not imply the expression of any opinion whatsoever on the part of the MedECC and its supporting institutions concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Preferred citation

MedECC, 2024: Climate and Environmental Coastal risks in the Mediterranean. [Djoundourian, S., Lionello, P., Llasat, M.C., Guiot, J., Cramer, W., Driouech, F., Gattacceca, J.C., Marini, K. (eds.)]. MedECC Reports. MedECC Secretariat, Marseille, France, 306 pp., doi: 10.5281/zenodo.13754020

Editors:

Salpie DJOUNDOURIAN, Piero LIONELLO, Maria Carmen LLASAT, Joël GUIOT, Wolfgang CRAMER, Fatima DRIOUECH, Julie C. GATTACCECA, Katarzyna MARINI
Cover design and layout by **Zen design studio** (Marseille)
Copy-editing by **Connected Language Services**

Photo credits

Adobe Stock Photos

Supporting institutions

www.medecc.org
Enquires: contact@medecc.org

Special Report

Climate and Environmental Coastal Risks in the Mediterranean

Editors

Report Coordinators:

Salpie DJOUNDOURIAN *(Lebanon)*, **Piero LIONELLO** *(Italy)*, **María Carmen LLASAT** *(Spain)*

MedECC Coordinators:

Joël GUIOT *(France)*, **Wolfgang CRAMER** *(France)*, **Fatima DRIOUECH** *(Morocco)*,

MedECC Scientific Secretariat:

Julie GATTACCECA *(France)*, **Katarzyna MARINI** *(France)*

by MedECC
Mediterranean Experts on Climate
and environmental Change

Union for the Mediterranean
Union pour la Méditerranée
الاتحاد من أجل المتوسط

UN environment programme

Mediterranean Action Plan
Barcelona Convention

Plan Bleu

Table of contents

Chapter 3 131

Impacts and risks

Chapter 4 209

Managing climate and environmental risks

Foreword

Climate change, natural disasters, and environmental degradation linked to pollution have multiple direct and indirect impacts on the coastal ecosystems and the health and well-being of coastal populations along the Mediterranean basin. This special report identifies the drivers of change in the coastal areas and their interactions. The findings indicate that the Mediterranean coastal areas are vulnerable to flooding and erosion, seawater intrusion, general degradation of coastal habitats, invasion of non-indigenous species, coastal squeeze, water shortage and cumulative pollution attributed to agricultural, urban and industrial practices.

Coastal communities will bear the immediate impact of coastal resource degradation. They will suffer most from rising sea level as well as severe weather events such as storm surges and tsunamis. The special report addresses the hazards posed by the drivers and their interactions as well as their observed impact and the future risks on the natural, socioeconomic and human systems. It indicates that community and resource resiliency depend mainly on the preparedness of communities and the adaptation measures in place, in addition to the vulnerability of the exposed entities, the frequency of exposure to consecutive events and the extent of damages. The special report presents and discusses particular strategies used in the Mediterranean Coast to manage climatic and environmental risks. It highlights the need for mitigation measures to reduce the probability of resource degradation, and adaptation measures to reduce the losses and damages resulting from resource degradation. It also identifies barriers to effective responses in the Mediterranean region.

The attainment of climate resilient sustainable development pathways in the coastal areas of the Mediterranean remains a serious challenge. Risks are expected to increase in the near future based on the projected climate change scenarios and the environmental changes linked to urban and coastal population growth whose distributional effects have an important policy dimension. Policy development, regional cooperation and proper communication to support greater integration of knowledge are fundamental to achieve sustainable coastal zone management practices.

This special report implicitly expresses our desire that coastal risks in the Mediterranean be addressed in such a way that the Mediterranean coast becomes a paradigm of peace, good coexistence and respect for life, cultures and the environment. This and other initiatives are examples of how scientific cooperation between different communities, countries and disciplines can be productive and very powerful for addressing environmental issues and is beneficial for all countries.

MedECC Coordinators:
Wolfgang CRAMER,
Fatima DRIOUECH,
Joël GUIOT

Report Coordinators:
Salpie DJOUNDOURIAN,
Piero LIONELLO,
María Carmen LLASAT

Statements from key partners

The Mediterranean world is at the heart of adaptation to climate change. This is not an abstraction, nor a figment of the imagination. The torrential rains that ravaged the city of Valencia in Spain, killing more than two hundred people, are a reminder of the reality of a highly exposed basin. Mare Nostrum is exposed to the effect of the movement of the European and African tectonic plates and the fact that the air, and above all the water, is warming up faster than the rest of the planet. The risk here is multiplied tenfold by the high concentration of population on the coasts. The interaction between the hazard and issues at stake means that coastal risks are now considered to be a major civil protection issue.

This work will feed not only into the academic work of the Plan Bleu, but also into the revision of the new Mediterranean Strategy for Sustainable Development (MSSD 2026-2035), so that all the States can mobilize around genuine South/North cooperation. For that, we need new financial tools and means without them proposals raised will stay pious hopes. Thank you to the MedeCC for this report, which sounds like a trumpet from Jericho.

Mr Robin Degron
Director of Plan Bleu/RAC

The Mediterranean coastal zones represent a crucial interface between land and sea, where environmental, social, and economic dynamics intersect. These areas are facing increasing pressures from climate change, pollution, urbanisation, and unsustainable exploitation of resources. The need for scientific understanding of coastal risks and collaborative action have never been greater.

This Special Report, prepared by the Mediterranean Experts on Climate and environmental Change (MedECC), plays a vital role in shedding light on the vulnerabilities and risks that coastal zones face in the Mediterranean. It builds upon the foundational work of the Barcelona Convention, a framework that has guided regional cooperation for nearly five decades in protecting the Mediterranean's marine and coastal environments. This report intends to ensure that decision-makers are equipped with science-based insights that can drive effective, coordinated responses.

The importance of this report extends beyond environmental protection; it touches on the very sustainability and resilience of the communities that depend on healthy coastal ecosystems. By integrating this knowledge into policies, the Mediterranean can better prepare for the impacts of climate change, ensure the protection of its coastal biodiversity, and foster sustainable development, towards effective SDGs implementation at regional scale.
As we move forward, the findings of this report will serve as a valuable tool for governments, stakeholders, and citizens alike. It is only through collaborative regional efforts and evidence-based policymaking that we can safeguard the future of the Mediterranean's coastal zones.

Ms Tatjana Hema
UN Environment Programme/ Mediterranean Action Plan (UNEP/ MAP) Coordinator

As we stand at a critical crossroad facing escalating environmental and climate catastrophes, this new report on Mediterranean coastal risks comes as an immediate call for action on our collective responsibility. The Mediterranean region is not only a cornerstone region where cultures, economies and ecosystems converge but also a vital hub for millions of people who depend on its coastlines for their livelihoods, heritage and shared prosperity. With temperatures rising well above the Paris Agreement's 1.5ºC threshold, the window of opportunity for action is rapidly closing. The projected sea-level rise and acceleration of extreme weather events threaten our communities, and economies. With its unwavering support for the MedECC and the backing of this report, the Union for the Mediterranean calls for a unified, urgent and ambitious regional response. Political leaders must step up and address both the present and future challenges with a collaborative approach to implement effective adaptation and mitigation strategies. The urgency of the climate crisis we face demands immediate steps which are critical to safeguard our shared Mediterranean future. We must transform the Mediterranean from a "hot spot" to a hope spot". This can only be achieved together, by increasing regional cooperation, investing in sustainable practices and prioritizing the resilience of our communities. The findings presented in the report call for all stakeholders to engage in rapid transformative measures. We need to act now, choosing cooperation over division and sustainability over short term goals. We must rise up to the challenge and protect our coastlines, support our vulnerable communities, and safeguard the Mediterranean cultural heritage and biodiversity.

Mr Nasser Kamel
Secretary General of the Union for the Mediterranean (UfM)

Preface

MedECC

The **Mediterranean Experts on Climate and environmental Change (MedECC)** is an open and independent international network of scientists founded in 2015, that specifically focuses on climate and environmental changes within the Mediterranean region. The objective of MedECC is to provide decision-makers, stakeholders, and citizens with assessments of available scientific knowledge on climate and environmental changes including associated risks and social aspects. MedECC reports aim to maintain neutrality regarding policy and to objectively address scientific, technical and socio-economic factors relevant to the application of policies. They are produced for use by policymakers and a broader audience, developed on the basis of scientific criteria only.

Since its creation, more than 300 authors have contributed to MedECC reports, all in an individual capacity and without financial compensation. MedECC scientists are located in 35 countries, including 19 registered as Contracting Parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) and 23 members of the Union for the Mediterranean (UfM).

The network is governed by Co-Coordinators, a Steering Committee, and an Advisory Board. Operations are managed by the MedECC Secretariat, which is officially hosted by Plan Bleu, a UNEP/MAP Regional Activity Centre in Marseille, France, as part of a partnership with the Secretariat of the Union for the Mediterranean (UfM). The Mediterranean Action Plan of the United Nations Environment Program (UNEP/MAP) has also provided support since 2022, with MedECC activities integrated into the UNEP/MAP Work Programmes for 2022-2023 and 2024-2025, approved during COP 22 (Antalya, Türkiye, December 2021) and COP 23 (Portorož, December 2023).

MedECC published the ***First Mediterranean Assessment Report (MAR1): Climate and Environmental Change in the Mediterranean Basin – Current situation and risks for the future,*** in November 2020. It includes a Summary for Policymakers (SPM) that has been approved line-by-line during a plenary session attended by government representatives from Mediterranean countries in September 2020, ensuring its relevance to stakeholders. MedECC was awarded the prestigious North-South Prize 2020 of the Council of Europe for its efforts towards peace and democracy. The SPM was recognised as an important contribution of the scientific community to future climate and environmental action in the Mediterranean region in the Declaration adopted during the 2nd Ministerial Meeting on Climate and Environmental Action of the Union for the Mediterranean (4 October 2021, Cairo, Egypt), and Contracting Parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) and its Protocols at their 22nd meeting (COP 22, December 2021, Antalya, Türkiye). The findings of MAR1 have since been widely acknowledged and cited in strategic documents, establishing it as a foundational scientific source for climate and mitigation policies across the Mediterranean.

The MAR1 report has laid significant groundwork for other major contributions in the Mediterranean. MedECC contributed to the coordination of the climate change chapter in the State of the Environment and Development in the Mediterranean (SoED) report, published in 2020. MedECC authors contributed to the IPCC sixth assessment report (AR6-WG2) published in February 2022, contributing a cross-chapter paper specifically focused on the Mediterranean Basin, integrating regional aspects into the global assessment.

The Portorož Ministerial Declaration, signed by the Ministers of the Environment and Heads of Delegation of the Contracting Parties to the Barcelona Convention during COP 23 (5-8 December 2023, Portorož, Slovenia) emphasises the need to enhance actions against climate change in the Mediterranean and to protect marine ecosystems from its harmful impacts. It calls for a strengthening of scientific knowledge and expertise in this area, highlighting initiatives like MedECC (Decision UNEP/MED IG.26).

This Special Report

The Special Report ***Climate and Environmental Coastal Risks in the Mediterranean*** responds to the MedECC Steering Committee's decision to provide scientific information to specific issues for the Mediterranean identified after the publication of MAR1, informed by both scientists and government representatives. It provides an assessment of the scientific, technical and socio-economic literature on environmental and climate change risks in the Mediterranean Basin's coastal zones. It builds upon the MedECC MAR1 report, previous reports by the Intergovernmental Panel on Climate Change (IPCC), and other relevant regional, national, and local assessments, and is drawing on evidence from over 1000 scientific publications.

Scope of the Report

A third of the Mediterranean population (around 150 million people) lives close to the sea and depends on coastal resources for its survival and livelihood. The coastal zone of the Mediterranean Sea is affected by multiple drivers of change: climate, pollution, biologic and socio-economic processes. This report describes their evolution, their impacts on ecosystems and people, the risks that are posed and solutions to reduce them, together with pathways for sustainable development. Adaptation actions are presented, placing social and cultural values in the context of the region and its local traditions. The report considers the need to protect communities, minimise impacts on the natural environment, and address ethical considerations important for socially oriented adaptation policies.

The available knowledge concerning the risks studied by MedECC contains significant gaps, often due to limited monitoring systems and scientific research capacity — these gaps have been communicated as clearly as possible. The best efforts have been made to provide complete and correct information, in spite of the gaps and uncertainty caused by the evolving nature of the knowledge, the limited monitoring systems and scientific research capacity, which have been communicated as clearly as possible.

Structure of the Report

The report consists of five Chapters, with additional annexes. It includes a Summary for Policymakers that is composed of headline statements and narrative of the key messages of the longer report and provides an executive summary of the report.

The introduction *(Chapter 1)* provides the context, background and key dimensions of this assessment. *Chapter 2* assesses the main drivers of climate change and environmental coastal risks in the Mediterranean and their changes. *Chapter 3* assesses the impacts of these drivers, and the risks posed on both interconnected human and natural systems. Chapter 4 assesses the existing and prospective responses and management approaches to address these risks. The final chapter *(Chapter 5)* synthesises the available knowledge about climate-resilient and sustainable development pathways, building on the outcomes of *Chapters 2* to *4*. This structure aims to propose a coherent assessment of the risks and responses for ecosystems, water, food, cities, human health, and livelihoods, efficiently to guide policymakers and stakeholders toward resilient and sustainable futures.

The Process

The Special Report represents the collaborative efforts of a team of leading experts and scientists who volunteered their time and expertise without financial compensation. Its preparation followed the established principles of scientific assessments, similar to those applied for MAR1 and the IPCC, involving an open and rigorous process of author selection, external peer-review, and stakeholder consultation. An open call for self-nominations of scientific experts was circulated in April 2021. The Scoping Meeting, held in July 2021, brought together experts, scientists, government representatives, and other stakeholders to identify key topics, chapters, and major questions that the report should address. The initial draft outline was reviewed and approved by the MedECC Steering Committee. Authors were also selected and approved by the MedECC Steering Committee based on their expertise, their country and the gender, resulting in a task force of 56 authors from 17 countries. The detailed content of the report was further refined during in-person meeting in Spain in June 2022, held jointly with the authors of two other MedECC Special Reports[1], and through a consultation with stakeholders, including members of the UfM Climate Change Expert Group (CCEG), UNEP/MAP and Plan Bleu focal points, and members of the Mediterranean Commission on Sustainable Development (MCSD).

The development of the Special Reports involved several stages of drafting, an open and transparent review and revision process, and consultation with stakeholders to ensure scientific accuracy and robustness, as well as strong policy-relevance. The initial draft (Zero Order Draft) underwent internal review in December 2022, receiving 479 comments from 15 reviewers. The First Order Draft report and its Summary for Policymakers (SPM) underwent extensive peer review and stakeholder consultation between May and July 2023. In total, 820 comments on the full report and 247 comments on the SPM were submitted by 50 reviewers. Authors revised the chapter drafts, addressing every comment thoroughly, and the SPM was concluded during an online plenary consultation with key stakeholders on November 7, 2024. These included MAP Focal Points, Plan Bleu Focal Points, members of the Mediterranean Commission on Sustainable Development (MCSD), MAP Partners, as well as members, observers, and partners of the UfM Climate Change Expert Group (UfM CCEG) and the UfM Working Group on Environment and Climate Change (WG ENV-CC), among other MedECC partners.

The Summary for Policymakers of the Special Report was approved by the Contracting Parties of the Barcelona Convention during their 23rd Meeting (Decision IG.26/13, COP 23, Slovenia, 5-8 December 2023).

---

[1] MedECC Special Report *Interlinking climate change with the Water - Energy - Food - Ecosystems (WEFE) nexus in the Mediterranean Basin*, 2024: https://www.medecc.org/medecc-reports/climate-wefe-nexus and MedECC *Expert analysis on the nexus between environmental change, conflict, and human migration* (in finalisation stage).

Acknowledgements

The MedECC report is the result of extensive efforts by numerous individuals, supported by esteemed institutions. The editors wish to express their deepest appreciation to the Coordinating Lead Authors and Lead Authors for their invaluable expertise and dedication throughout the process. Their work was facilitated by the Contributing Authors who assisted in drafting the report. We are grateful to the experts and government reviewers whose insightful feedback on the drafts significantly enhanced the quality of the report. We would also like to acknowledge the support of the MedECC Steering Committee, for their oversight of the process.

We sincerely acknowledge the support from the contributing institutions, particularly Plan Bleu, which hosts the MedECC Secretariat, the Union for the Mediterranean (UfM) with funding from the Swedish International Development Cooperation Agency (SIDA), and the United Nations Environment Programme/Mediterranean Action Plan (UNEP/MAP). The MedECC also benefits from the funding from the French Agency for Ecological Transition (ADEME), the French Ministry of Ecological Transition and Territorial Cohesion, the French Ministry for Europe and Foreign Affairs (MEAE), the Italian Ministry of Environment and Energy Security (MASE), the Principality of Monaco, the French Rhone Mediterranean Corsica water agency, and the Mediterranean Trust Fund (MTF). MedECC is also supported by the Advisory Council for the Sustainable Development of Catalonia (Government of Catalonia, Spain), the Association pour l'Innovation et la Recherche au service du climat (AIR Climat), and IT Department of OSU Pythéas (France).

We would like to extend our special recognition to individuals who provided consistent and valuable support in advancing MedECC and its science-policy interface, especially within Plan Bleu: Robin Degron and François Guerquin, current and former Director, Antoine Lafitte and Lina Tode, current and former Deputy Director; and within the UfM Secretariat: Grammenos Mastrojeni, Deputy Secretary General for Energy and Climate Action, along with Marie-Claire Boillot, Senior Expert on Energy and Climate Action, and Arnault Graves, former Senior Climate Adviser. We also acknowledge the UNEP/MAP Coordinating Unit, especially Coordinator Tatjana Hema, as well as Ilias Mavroeidis and Julien le Tellier, current and former Programme Management Officer respectively. The refinement of the Summary for Policymakers (SPM) was further enhanced by a day-long discussion with stakeholders, including governmental Focal Points, chaired by Marie-Claire Boillot (UfM) and Lina Tode (former Plan Bleu).

We gratefully thank the following individuals who provided their invaluable help and assistance for the Coordinating Lead Authors in-person meeting, held in Barcelona (Spain) in June 2022: María Carmen Llasat (University of Barcelona, Spain) and Arnau Queralt Bassat (Advisory Council for the Sustainable Development of Catalonia, Government of Catalonia, Spain), Sandra Dubelcco and Yasmine Hadj Larbi (Plan Bleu, France).

We are grateful to those involved in communicating about MedECC and its reports, including the Plan Bleu communication team, especially Pauline Simon and Christelle El Selfani, as well as the UfM communication team, especially Isabel Pardillos, Ainhoa Goma, and Cristina Tomàs White.

Our thanks extend to Isabelle Rossi and Sandra Dulbecco (Plan Bleu) and Antoine Nicault, Sébastien Bergé-Lefranc, and Célia Masson (AIR Climat) for their valuable assistance with accounting and administrative matters.

Additionally, we wish to acknowledge the support from Marie-Charlotte Bellinghery (MACHA), the team of Connected Language Services, Marion Dejean (Madehok), Chloé Gaillard, Pierick Jeannoutot (Zen Studio), Emma Johansson, Nicolas Léon (Omnitic), and Stéphanie Wicha.

List of figures, tables, and boxes

Figures

Tables

Boxes

Climate and environmental coastal risks in the Mediterranean

Summary for Policymakers (SPM)

Drafting Authors

Salpie DJOUNDOURIAN *(Lebanon)*, **Piero LIONELLO** *(Italy)*,
María Carmen LLASAT *(Spain)*, **Mohamed ABDRABO** *(Egypt)*,
Murat BELIVERMIS *(Türkiye)*, **Z. Selmin BURAK** *(Türkiye)*,
Dario CAMUFFO *(Italy)*, **Nathalie HILMI** *(Monaco)*, **José A. JIMÉNEZ** *(Spain)*,
Suzan KHOLEIF *(Egypt)*, **Stefano MONCADA** *(Malta)*, **Anna PIRANI** *(Italy)*,
Agustín SÁNCHEZ-ARCILLA *(Spain)*, **Athanasios T. VAFEIDIS** *(Germany/Greece)*

Editors

Salpie DJOUNDOURIAN *(Lebanon)*, **Piero LIONELLO** *(Italy)*,
María Carmen LLASAT *(Spain)*, **Joël GUIOT** *(France)*,
Wolfgang CRAMER *(France)*, **Fatima DRIOUECH** *(Morocco)*,
Julie GATTACCECA *(France)*, **Katarzyna MARINI** *(France)*

This document should be cited as:
MedECC, 2024: Summary for Policymakers. In: *Climate and Environmental Coastal Risks in the Mediterranean.* [Djoundourian, S., Lionello, P., Llasat, M.C., Guiot, J., Cramer, W., Driouech, F., Gattacceca, J.C., Marini, K. (eds.)]. MedECC Reports. MedECC Secretariat, Marseille, France, 19-40 pp., ISBN: 978-2-493662-03-3, doi: 10.5281/zenodo.10722133

Text as approved during the Plenary Session of MedECC Stakeholders on November 6, 2023, and endorsed (Decision IG.26/13) at the 23rd Meeting of the Contracting Parties to the Barcelona Convention and its Protocols (COP 23, Slovenia, 4–8 December 2023).

Table of contents

List of figures

Executive Summary: climate and environmental coastal risks in the Mediterranean Basin

The coastal zone of the Mediterranean Sea is affected by multiple drivers of change: climate, pollution, biologic and socio-economic processes *(Figure SPM1).* This report describes their evolution, their impacts on ecosystems and people, the risks that are posed and solutions to reduce them, together with pathways for sustainable development *(Figure SPM2).*

The Mediterranean coastal region is characterised by rapid, spatially diverse and geographically unbalanced socioeconomic development, mainly related to demographic trends, human settlement patterns and on-going wars and armed conflicts in different countries. The total coastal population of the Mediterranean is expected to grow faster than the inland population, thus leading to increased exposure of people and assets to coastal hazards. The northern Mediterranean may experience coastal population decline under some scenarios, while the highest increases in coastal population are expected in the Mediterranean Middle Eastern and Maghreb countries.

Climate change is affecting both the terrestrial and marine components of the Mediterranean coastal zone. Projections show an increase in surface air temperatures, frequency and intensity of hot extremes, sea level, evapotranspiration and decreased precipitation, depending on the level of future greenhouse gas emissions. Climate change is expected to pose serious risks for ecosystems and important economic sectors such as summer beach tourism, agriculture, aquaculture and fisheries.

The Mediterranean coastlines have experienced an accelerating relative sea level rise, which is expected to continue during the coming decades and centuries. Rising sea levels will exacerbate the risks of coastal floods, permanent inundation of some areas, and coastal erosion, with consequences for ecosystems and efficiency of present defences. Coastal structures, such as airports, transport networks, ports, and cultural heritage sites will be at risk. Both protection against coastal flooding and management of coastal erosion generally do not adequately consider future sea level rise, with risks of limited future efficiency. Climate change and growing urbanisation will further increase the risk posed by flash floods in some coastal areas.

Risks of water scarcity in the coastal areas of the Mediterranean are caused by the overall drying trend affecting the region, salinisation of coastal aquifers, increasing demand associated with population growth, irrigation, tourist use, industry and the energy sector. Risks of water scarcity are expected to increase in the future. Adaptation to decreasing water availability is taking place in Mediterranean coastal areas, with needs that vary significantly across sub-regions, depending on the population dynamics, the hydrogeological context and water management practices. These adaptation options consist in increasing water supply, improving water quality, supporting measures and governance, and to a lesser extent, reducing water demand.

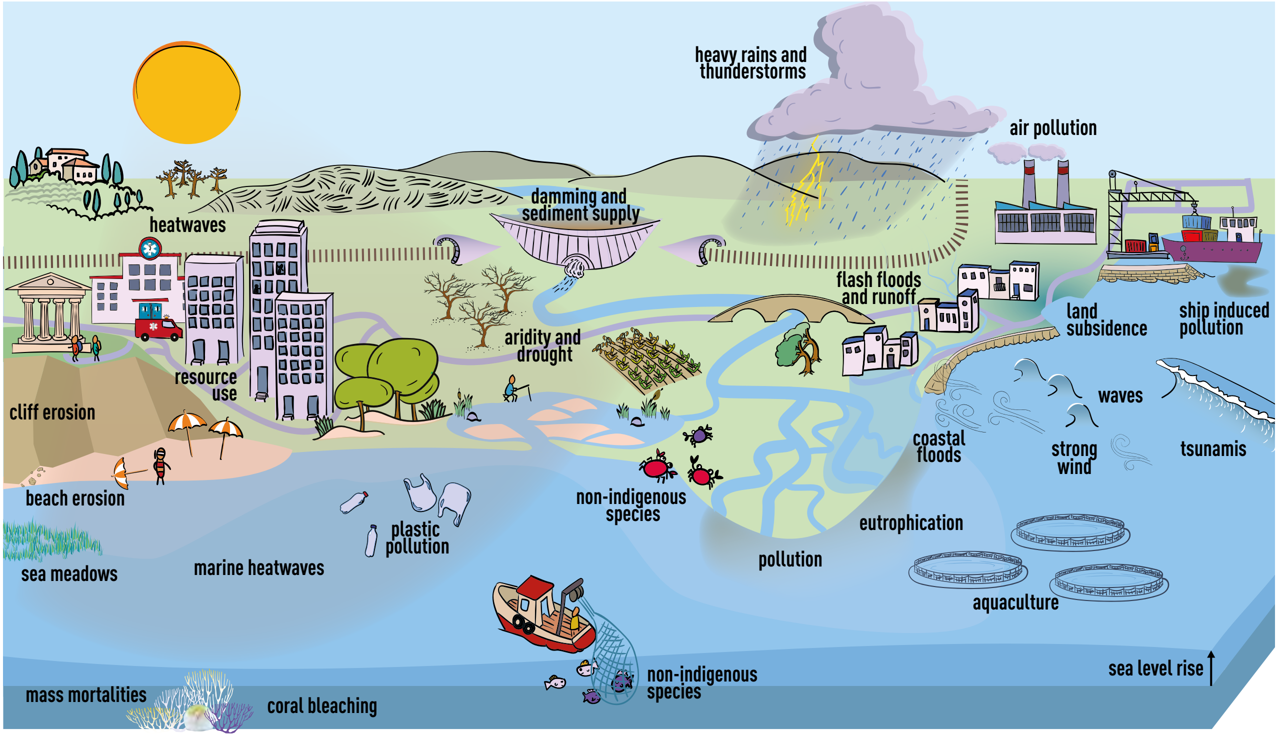
In the Mediterranean Sea, observed mass mortalities in coastal waters have been partially attributed to marine heat waves and are expected to increase in the future. Mediterranean coastal wetlands have significantly declined since the beginning of the 20th century and further reduction is expected in the future. The efficiency of the conservation measures in coastal ecosystems strongly depends on the success of climate change mitigation and an increasing number of hard limits will be reached for every increment of global warming. The Mediterranean is also becoming increasingly colonised by non-indigenous tropical species and changes in the distribution and population of species have been observed. However, solutions have been rarely attempted.

Mediterranean coastal areas are polluted by micro- and macro-plastics, metals, persistent organic pollutants and emerging pollutants, with nutrient inputs from land, producing eutrophication in several coastal areas with negative impacts on ecological systems, human health and economic sectors (aquaculture, fishing, and coastal tourism). Pollution originates from numerous human activities, which are mainly land-based, such as industry, agriculture, urbanisation, and tourism. Future pollution levels along the Mediterranean coasts are expected to exhibit varying trends across regions and pollutants, depending on regulations, dependency, production, treatment, and socioeconomic changes. Pollution control at its source is generally more efficient than treating it at the endpoints. Actions to tackle pollution at a Mediterranean basin-scale have not been implemented yet, and both technical and decision-making challenges remain.

The engagement of scientists with policymakers, stakeholders, and citizens is a key factor to removing barriers (including lack of understanding and trust) and can be particularly beneficial during the planning process. Turning stakeholders into partners significantly increases the potential of successfully implementing solutions and adaptation measures.

In the Mediterranean coastal zone, present actions towards solutions to environmental problems, adaptation to climate change and its mitigation are insufficient to attain the UN Sustainable Development Goals (SDGs) ensuring the well-being of people and the sustainability of resources. Without transformative actions across all sectors, systems, and scales, climate change risks will be exacerbated, and the sustainable development goals will not be met. Social-economic and gender-based inequalities, lack of access to basic services will act as further barriers to the implementation of sustainable development pathways.

Adopting actions consistent with sustainable development pathways requires the proper identification of vulnerabilities related to human activities and climate change impacts, and assessment of options to reduce risks to the affected communities and ecosystems. A mix of legal, policy and economic instruments, and behavioural nudges are available at local, national, and regional level to promote effective and resilient development pathways in the Mediterranean coastal zone.



Aridity and droughts: future reduced precipitation, associated with increased evapotranspiration will lead to droughts, drier soils, decline of runoff and of coastal freshwater supply.

Aquaculture: more than 100 species (finfish, shellfish, crustaceans and algae) are currently cultivated in the Mediterranean.

Coastal erosion: in the future the projected median value of shoreline retreat for the Mediterranean with respect to present is 65 m by 2100 under a very high emission scenario.

Coastal floods: the frequency of an extreme sea level event that occurs one in a 100 year is likely to increase 65% by the end of the 21st century under the very high greenhouse gas emission scenario.

Flash floods: risks posed by flash floods are high in several Mediterranean coastal stretches. Without efficient adaptation, flash flood risks are expected to increase in relation to the increase in the frequency of heavy rainfalls and population density in flood prone coastal areas.

Marine warming and heat waves: since the 1980s sea surface warmed in the range from +0.29°C and +0.44°C per decade. Over the last two decades the frequency of marine heat waves increased by 40%. The mean sea surface temperature of the Mediterranean Sea is expected to increase by the end of the 21st century in the range 2.7°C to 3.8°C under the very high greenhouse gas emissions scenario.

Mass mortalities: observed mass mortalities in Mediterranean coastal waters have been partially attributed to marine heat waves and are expected to increase in the future.

Non-indigenous species: over a thousand of non-indigenous species have been identified in the Mediterranean and along its coasts. Warming of the Mediterranean waters is creating increasingly suitable conditions for non-indigenous thermophilic species.

Plastic pollution: plastics account for up to 82% of observed litter, 95–100% of total floating marine litter and more than 50% of seabed marine litter in the Mediterranean Sea. By 2040 plastic pollution is likely to double if annual plastic production continues to grow at a rate of 4% and plastic waste management is not radically improved.

Pollution is originated from numerous human activities, mainly land-based, such as industry, agriculture, urbanisation, and tourism Future pollution levels along the Mediterranean coasts are expected to exhibit varying trends across regions and pollutants, depending on regulations, decreasing dependency, diminishing production and socioeconomic changes.

Population: the total population of Mediterranean countries in 2020 was about 540 million people, around one-third of them living in the coastal zone. Up to 20 million people could be affected by permanent displacement due to sea-level rise by 2100.

Salinisation of aquifers: seawater intrusion in coastal aquifers affects a great part of the Mediterranean coast. In the future, salinisation of aquifers could further increase in the coastal areas affected by relative sea level rise.

Sea level rise: mean sea level in the Mediterranean has risen at about 1.4 mm yr^{-1} during the 20th century and has accelerated to about 2.8 mm yr^{-1} in the last three decades. At the end of the 21st century, the Mediterranean mean sea level is projected to likely increase 0.6–1.0m relative to present under the very high greenhouse gas emission scenario.

Sea water acidification: seawater acidification is projected to continue and pH will change between −0.25 and −0.46 pH units in Mediterranean surface waters by the end of the century compared to pre-industrial era in very high emission scenarios.

Wetland: Mediterranean coastal wetlands have experienced a substantial decline, losing approximately 50% of their area during the 20th century.

Figure SPM1 | The coastal zone and drivers of environmental and climate change.

A. Framing: scope and basic concepts

A.1 This Special Report identifies and assesses environmental and climate change hazards in the coastal zone of the Mediterranean Basin, the related risks, adaptation options and solutions. It further assesses and provides information on actions to meet the United Nations Sustainable Development Goals (SDGs), such as combating climate change, increasing food security, ensuring water resources, accessing affordable and sustainable energy resources, managing natural resources, creating opportunities for social inclusion, and economic prosperity. Adaptation plans are presented by placing the social and cultural values in context of the region and its local traditions, considering the need to protect communities and biodiversity, minimise impacts on the natural environment, and addressing ethical considerations important for socially-oriented adaptation policies. ***(Figures SPM1, SPM2)***

A.1.1 Policies to manage coastal risks and adaptation strategies in the Mediterranean coastal zone are important to the whole region, as a third of the Mediterranean population lives close to the sea and depends on infrastructure and economic activities in its immediate vicinity.

A.1.2 The coastal zone can be defined using objective and subjective criteria, often with a high level of uncertainty or fuzziness. Depending on the technical, economic or legal implications, the definition and extent of the coastal zone may vary significantly in the literature. This report does not aim to propose a general definition, instead it adopts a loose criterion that the coastal zone consists of areas geographically connected to the coastline, including land areas directly impacted by marine processes and sea areas directly impacted by terrestrial processes.

A.1.3 The Mediterranean coastal zone is often narrow and over-pressured and requires a specific risk assessment tailored to its characteristics to inform adaptation pathways and support decisions towards risk reduction and sustainability in coastal governance, policies and social perception.

A.2 This Special Report, as with other MedECC assessments, and international and national assessment processes, is based on the available, relevant and traceable evidence in the published scientific literature, including different lines of evidence (observational products, model-based findings and other types of data and analyses).[2]

A.2.1 This report applies the calibrated terms that were adopted transversally by the Intergovernmental Panel on Climate Change (IPCC) since the 5th Assessment Report in order to communicate the robustness and certainty of assessment findings either qualitatively or quantitatively. The calibrated terms quantify confidence and likelihood[3]. The terms are attributed to the assessment outcome by the author team following an evaluation of the available evidence. The designation of confidence and likelihood are agreed upon through a consensus-building discussion of the evidence, reflecting all expert views that are expressed.

A.2.2 A common set of key dimensions is used in this report on the basis of information that is available in the scientific literature, including well-defined time frames, baselines for past changes and conditions, a subset of representative scenarios of future changes, and well-known frameworks, such as the Sustainable Development Goals (SDGs).

A.2.3 Shared Socioeconomic Pathways (SSP) are cited as defined in IPCC AR6 based on future greenhouse gases (GHG) emissions, labelled after the SSP narrative and associated radiative forcing values in the year 2100 (1.9, 2.6, 4.5, 7.0, and 8.5 W m^{-2}): SSP1-1.9 - very low GHG emissions and SSP1-2.6 – low GHG emissions (CO_2 emissions reduce to net zero in the 2050s), SSP2-4.5 – intermediate GHG emissions (CO_2 emissions remain around current

---

[2] The scientific evidence for each key finding is found in the chapters of the underlying report and referred to in curly brackets {}.

[3] Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or result: virtually certain 99–100% probability; very likely 90–100%; likely 66–100%; about as likely as not 33–66%; unlikely 0–33%; very unlikely 0–10%; and exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%; more likely than not >50–100%; and extremely unlikely 0–5%) are also used when appropriate. Assessed likelihood is typeset in italics, for example, *very likely*.

levels until 2050, then falling but not reaching net zero by 2100), SSP3-7.0 – high GHG emissions and SSP5-8.5 – very high GHG emissions (CO_2 emissions roughly double from current levels by 2100 and 2050, respectively).

A.2.4 Representative Concentration Pathways (RCP) defined in IPCC AR5 are cited. RCPs are greenhouse gas concentration (not emissions) trajectories labelled by the associated radiative forcing values in the year 2100 (2.6, 4.5, 6, and 8.5 W m^{-2}), respectively and corresponding to one stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5).

B. Present status of the climate and environmental drivers for the coastal area

B.1 Climate change is affecting the whole Mediterranean environment, including the terrestrial and marine components of its coastal zones. *(Figure SPM3)* {2.2}

B.1.1 Overall, the increasing trend of the period 1970–2019 implies that the 30-year average surface air temperatures of the Mediterranean region in 2020 was 1.5°C warmer than the pre-industrial period 1860–1890, with an increasing trend of the order of 0.01–0.05°C yr^{-1} since the 1980s *(high confidence)*. {2.2.1}

B.1.2 The change in Mediterranean Sea surface temperatures has been characterised by multidecadal variations superimposed by a long-term positive trend since the pre-industrial period with an increase of about 0.86°C in 100 years *(high confidence)*. Satellite data since the 1980s show spatially different warming rates of the sea surface between +0.29°C and +0.44°C per decade, and higher in the eastern Mediterranean. Over the last two decades the frequency and duration of marine heat waves increased by 40% and 15%, respectively *(high confidence)*. {2.2.1, 2.2.5}

B.1.3 The magnitude and pattern of the observed precipitation trends over the Mediterranean exhibit pronounced spatial variability and depend on the time period and season considered *(high confidence)*. {2.2.2}

B.1.4 The estimated decrease in the pH of Mediterranean Sea surface waters is between 0.055 and 0.156 pH units since the preindustrial period *(high confidence)*. {2.2.5}

B.2 Mediterranean coastlines have experienced relative sea level rise, which is the sum of mean sea level rise and vertical land motion, with an accelerated rate during the last three decades (1993–2018). {2.2.7, 2.2.8}

B.2.1 Mean sea level in the Mediterranean shows an approximate trend of ~1.4 mm yr^{-1} during the 20th century *(high confidence)*, and has accelerated to 2.8 ± 0.1 mm yr^{-1} in the last three decades (1993–2018) *(high confidence)*. The interannual and decadal variability that is superimposed to this trend can temporarily mask it. {2.2.7}

B.2.2 Vertical land motion along the Mediterranean coasts generally ranges from 0 to −10 mm yr^{-1}, with isolated positive values. This widespread subsidence is mainly determined by geological factors such as tectonic subsidence and natural sediment compaction but is increased by human activities such as the withdrawal of underground fluids (water, oil and gas, drainage of organic soils) that contribute significantly to relative sea level rise in some areas[4] *(high confidence)*. {2.2.8}

B.2.3 Coastal flooding in the Mediterranean due to storm surges and wind waves threatens the flood-prone areas in the waterfronts (river mouths and deltas) and low-lying coastal plains in many Mediterranean countries. Relative sea level rise has already increased the frequency of floods of the Venice city centre, Italy *(high confidence)*. {2.2.4}

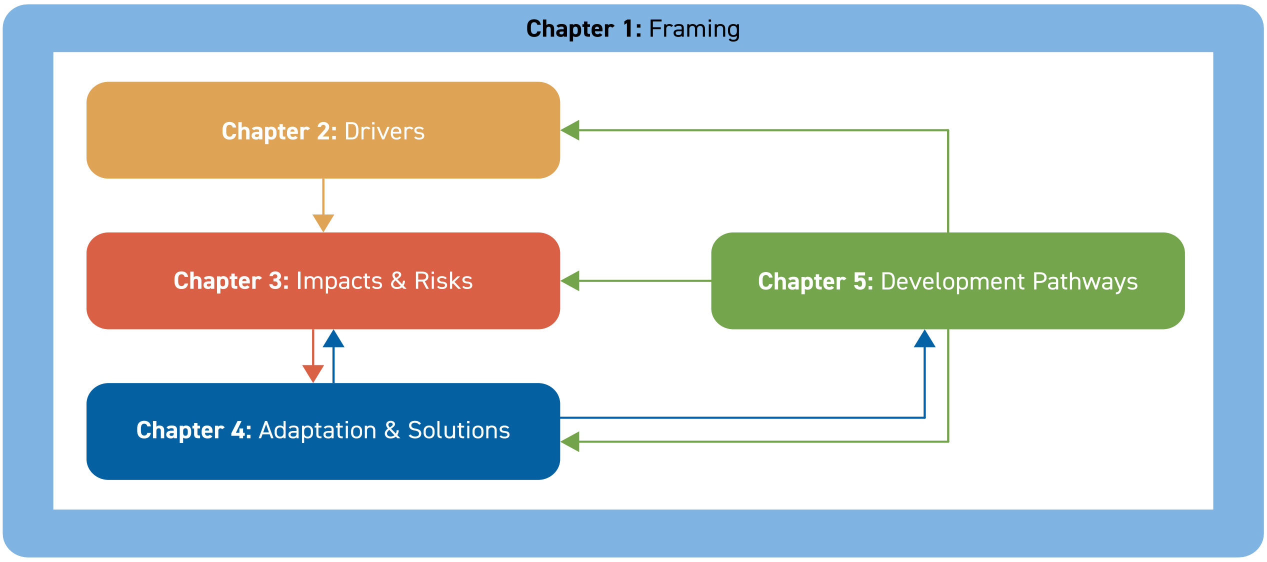
B.3 Mediterranean coastal areas are polluted by micro- and macro-plastics, metals, persistent organic pollutants and emerging pollutants from various sources, with nutrient inputs from land causing eutrophication in several coastal areas. *(Figure SPM3)* {2.4}

B.3.1 Coastal water pollution originates mainly from land-based sources, followed by air and ship-originated sources. Pollution sources include domestic effluents, agricultural runoff, road transport, maritime transport, mine tailings, manufacturing and extractive industries. {2.4}

---

[4] In the coastal region of the eastern Nile Delta in Egypt, Thessaloniki in Greece, the city of Venice, the Po Delta, the Arno River and the coastal plain of Catania in Italy, the Ebro Delta in Spain, and the Medjerda Delta in Tunisia.

STRUCTURE AND LOGICS OF THE REPORT
Themes and the main sections of the full report that deal with them



SUBJECT	CHAPTER 1 FRAMING	CHAPTER 2 DRIVERS	CHAPTER 3 IMPACTS & RISKS	CHAPTER 4 ADAPTATION & SOLUTIONS	CHAPTER 5 DEVELOPMENT PATHWAYS
Climate & Geology	1.2	2.2	3.2 | 3.3 | 3.4	4.2 | 4.5	5.2 | 5.3
Air temperature	1.2.1	2.2.1	3.5		
Precipitation		2.2.2		4.2.1	
Atmospheric circulation		2.2.3	3.2.3 | 3.3.5 | 3.4.1		
Cyclones		2.2.4	3.2.4		
Sea water temperature, salinity & acidification		2.2.5	3.2.3	4.2.5	
Surface water budget		2.2.6	3.2.5 | 3.2.6 | 3.3 | 3.4 | 3.5	4.2.4	
Sea level rise & (permanent) coastal submersion		2.2.7	3.2.5	4.2.2	
Natural & anthropic land subsidence		2.2.8	3.2.2 | 3.2.3 | 3.4.1 | 3.5.1 | 3.5.2	4.2.3	
Geohazards		2.2.9	3.2.2 | 3.2.3	4.5.1	
			3.2.4		
Biology		2.3		4.4	5.3
Non-indigenous species		2.3.1	3.2.7 | 3.4.2	4.4	
Species distribution		2.3.2	3.2.7		
Jellyfish blooms		2.3.3	3.2.7 | 3.3.3 | 3.5.2		
			3.2.7		
Pollution	1.2.2	2.4		4.3	5.3
Nutrients		2.4.1	3.2.6	4.3.1 | 4.3.2 | 4.3.3	
Trace metals		2.4.2	3.2.6	4.3.3	
Persistent organic pollutants (POP)		2.4.3	3.2.6	4.3.1 | 4.3.2 | 4.3.3 | 4.3.4	
Plastics		2.4.4	3.2.6	4.3.4	
Emerging pollutants		2.4.5	3.2.6	4.3.2 | 4.3.3	
Municipal waste			3.2.6	4.3.1	
Air pollution		2.4.6			
			3.2.6		
Economy & Society	1.2.3 | 1.3	2.5		4.3	5.3 | 5.4
Population growth	1.1.3	2.5.1	3.3 | 3.4 | 3.5		
Development trends	1.1.3	2.5.2	3.4.2		
Tourism & cruising		2.5.2.1	3.4.1		5.3.1.2
Maritime transport		2.5.2.1	3.3.1		
Oil & gas exploration and extraction		2.5.2.2	3.3.1		5.3.1.1
Sea water desalinization		2.5.2.3	3.3.4		
Food security			3.3.4		
Fisheries & aquaculture		2.5.2.4	3.3.2		5.3.1.3
Science-policy interface	1.1.2		3.3.3	4.7	
Transformative pathways for development	1.3.2				5.3.3
Social equity and climate justice	1.4.4				5.4

Figure SPM2 | Visual guideline to the content of the report.
Structure and logics of the report showing references to the sections of the full report in which the listed issues are addressed.

B.3.2 The Mediterranean Sea is one of the most heavily plastic polluted areas across the globe and floating plastics accumulate along its coasts as a result of human activities and marine circulation *(high confidence).* Plastics account for up to 82% of observed litter, 95–100% of total floating marine litter and more than 50% of seabed marine litter in the Mediterranean Sea. About two thirds of all the plastic debris from land-based sources (rivers, urban and industrial areas, and intensive agricultural areas) is retained along the coasts, where its level has remained steady for the past two decades, with several hotspots of plastic fluxes[5] *(medium confidence)*. {2.4.4}

B.3.3 Human activities have led to increased concentrations of potentially toxic metals with hotspots of lead, mercury and cadmium located on the northern, central and south-eastern shores of the Mediterranean Basin *(high confidence).* Manufacturing of refined petroleum products (southern Mediterranean, Balkans and Türkiye), tanning and dressing of leather, and manufacturing of cement (Balkans and Türkiye) and energy production (Mediterranean EU countries) contribute to the release of heavy metals in coastal waters impacting marine ecosystems. Mercury concentrations exceed European Union regulatory thresholds in many Mediterranean top-predatory fish. Methylated mercury concentrations in western Mediterranean waters are twice as high as in the eastern Mediterranean *(high confidence)* and are biomagnified in marine food webs *(medium confidence).* In general, the release of toxic metals is decreasing for the European Union countries, but opposite trends are reported in some areas *(high confidence).* {2.4.2}

B.3.4 Pollution sources such as domestic effluents, runoff from agricultural practices and urban runoff introduce emerging pollutants and persistent organic pollutants into the coastal zone, with higher concentrations in the northern than the southern shores. Pollution from polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) has been detected along some stretches of the Mediterranean coastline with the highest levels observed around river mouths, and harbour and industrial areas *(medium confidence).* Shipping is one of the main sources of oil pollution in Mediterranean coastal areas, with about 90% of tanker spills occurring near the coastlines and particularly affecting the eastern coasts *(medium confidence).* {2.4.3}

B.3.5 Nutrient flows of nitrogen and phosphate have decreased in most of the northern Mediterranean over the last two decades, following the implementation of best agricultural management practices and technological advances in wastewater treatment plants. However, nutrient pollution has increased in the southern and eastern Mediterranean in parallel with agricultural intensification and urban and industrial development *(high confidence).* {2.4.1}

B.4 Biological drivers in the Mediterranean and along its coast include the presence of over a thousand non-indigenous species, making it a major invasion hotspot, and jellyfish blooms. ***(Figure SPM3)*** **{2.3.2, 2.3.4}**

B.4.1 Non-indigenous species are accidentally introduced into Mediterranean coastal waters, estuaries or coastal lagoons, by aquaculture facilities, aquarium species trade, boat ballast waters and biofouling on vessels. Most non-indigenous subtropical coastal fish species enter the Mediterranean from the Red Sea. Warming of the Mediterranean waters is creating increasingly suitable conditions for non-indigenous thermophilic species, which are expanding their distribution ranges *(high confidence).* {2.3.2, 2.3.3}

B.4.2 The frequency of jellyfish blooms has increased in the Mediterranean Sea with some evidence that they benefit from eutrophication, warming of sea water and other human induced stressors *(medium confidence).* {2.3.4}

B.5 The Mediterranean coastal region is characterised by rapid, spatially diverse and geographically unbalanced socioeconomic development, mainly related to demographic trends, human settlement patterns and on-going wars and armed conflicts in different countries. ***(Figure SPM3)***

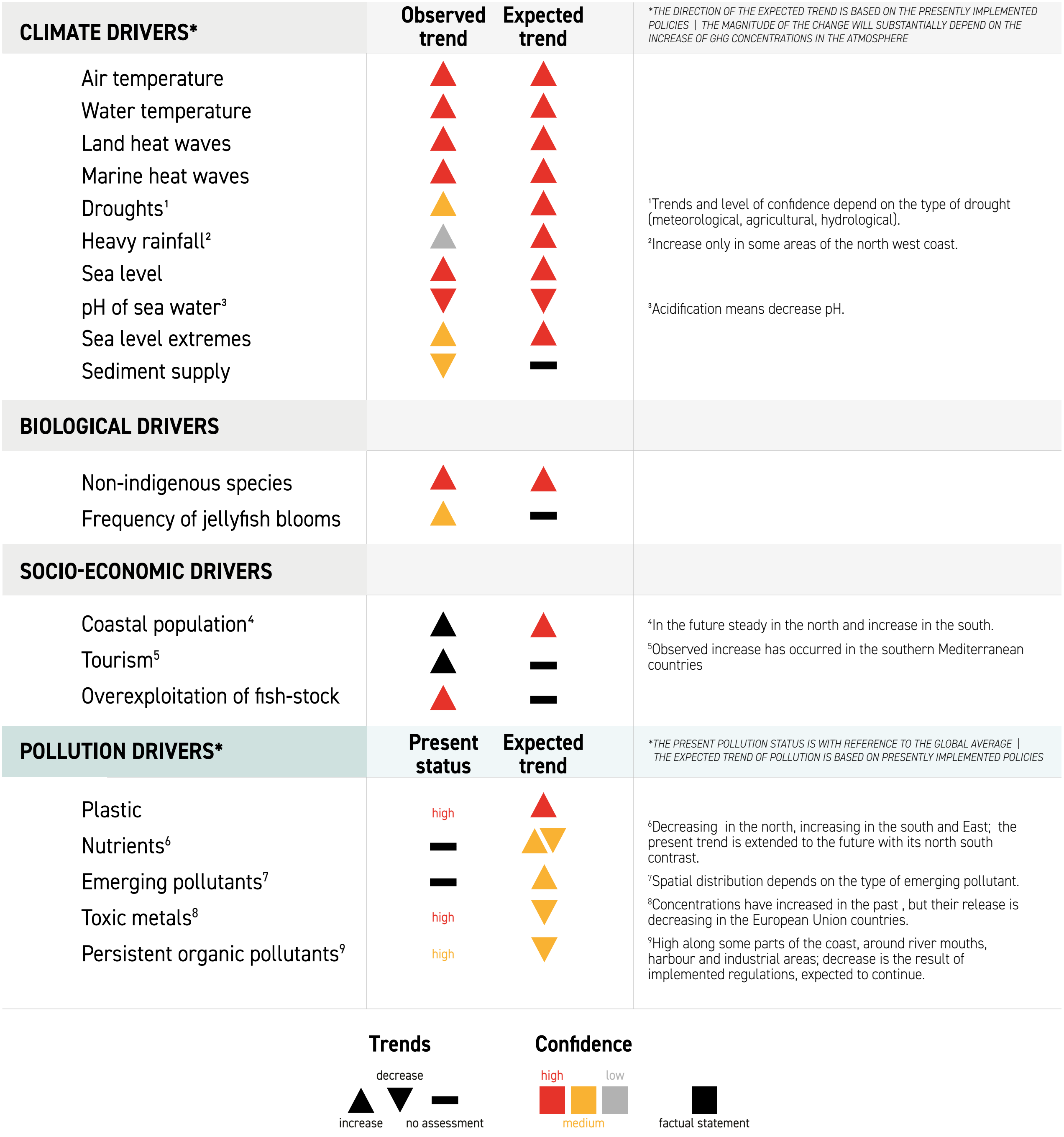
B.5.1 The total population of Mediterranean countries in 2020 was about 540 million people, around one-third of them living in coastal areas, with a high concentration of urban settlements near the coast. {2.5.1}

---

[5] The coastlines of Algiers in Algeria, Israel, Marche and the Po Delta in Italy, Barcelona in Spain, Bizerte in Tunisia, Mersin in Türkiye, and Syria.

B.5.2 The development gap between the northern, southern and eastern countries in terms of economic growth, income, population growth and education continues to persist and is further exacerbated by war and social unrest in several eastern and southern Mediterranean countries *(high confidence)*, potentially reducing the adaptive capacity to coastal hazards *(medium confidence)*. {2.5.2}

B.5.3 The Mediterranean is the world's leading tourism destination, both internationally (it attracts about one third of the world's tourism) and domestically, with over half of the EU's tourist accommodation establishments located in coastal areas. While the northern countries are mature/traditional tourism destinations, some southern countries, such as Egypt and Türkiye, have recently experienced a significant growth in coastal tourism. {2.5.2, 5.3.1}



CLIMATE DRIVERS*	Observed trend	Expected trend	*THE DIRECTION OF THE EXPECTED TREND IS BASED ON THE PRESENTLY IMPLEMENTED POLICIES | THE MAGNITUDE OF THE CHANGE WILL SUBSTANTIALLY DEPEND ON THE INCREASE OF GHG CONCENTRATIONS IN THE ATMOSPHERE
Air temperature	▲	▲	
Water temperature	▲	▲	
Land heat waves	▲	▲	
Marine heat waves	▲	▲	
Droughts[1]	▲	▲	[1]Trends and level of confidence depend on the type of drought (meteorological, agricultural, hydrological).
Heavy rainfall[2]	▲	▲	[2]Increase only in some areas of the north west coast.
Sea level	▲	▲	
pH of sea water[3]	▼	▼	[3]Acidification means decrease pH.
Sea level extremes	▲	▲	
Sediment supply	▼	▬	
BIOLOGICAL DRIVERS			
Non-indigenous species	▲	▲	
Frequency of jellyfish blooms	▲	▬	
SOCIO-ECONOMIC DRIVERS			
Coastal population[4]	▲	▲	[4]In the future steady in the north and increase in the south.
Tourism[5]	▲	▬	[5]Observed increase has occurred in the southern Mediterranean countries
Overexploitation of fish-stock	▲	▬	
POLLUTION DRIVERS*	**Present status**	**Expected trend**	*THE PRESENT POLLUTION STATUS IS WITH REFERENCE TO THE GLOBAL AVERAGE | THE EXPECTED TREND OF POLLUTION IS BASED ON PRESENTLY IMPLEMENTED POLICIES
Plastic	high	▲	
Nutrients[6]	▬	▲▼	[6]Decreasing in the north, increasing in the south and East; the present trend is extended to the future with its north south contrast.
Emerging pollutants[7]	▬	▲	[7]Spatial distribution depends on the type of emerging pollutant.
Toxic metals[8]	high	▼	[8]Concentrations have increased in the past , but their release is decreasing in the European Union countries.
Persistent organic pollutants[9]	high	▼	[9]High along some parts of the coast, around river mouths, harbour and industrial areas; decrease is the result of implemented regulations, expected to continue.

Trends

▲	▼	▬
increase	decrease	no assessment

Confidence

🟥	🟧	⬜	⬛
high	medium	low	factual statement

Figure SPM3 | Drivers of change and their expected evolution in the Mediterranean coastal zone.

B.5.4 The Mediterranean drainage basin incorporates more than 160 rivers, most of which are small and distributed across the European side of the Mediterranean coast. About 46% of the total length of the Mediterranean coastline has been formed by sediment deposition whose supplies have been significantly reduced by damming of Mediterranean rivers *(medium confidence)* {2.5.2}

B.5.5 The majority of fish stocks are overexploited *(high confidence)* which also poses serious economic problems. The most overexploited priority species in the Mediterranean is the European hake, which, due to its presence in most trawl fisheries, shows an average overexploitation rate 5.8 times higher than the sustainability target. {2.5.2}

B.5.6 The Mediterranean has experienced an upward trend in aquaculture production driven primarily by increased production in Egypt and Türkiye, followed by Greece, Italy, Spain, France and Tunisia. More than 100 species (finfish, shellfish, crustaceans, and algae) are currently cultivated within a wide range of environments and farming systems. {2.5.2}

C. Future evolution of climate and environmental drivers for the coastal area

C.1 Surface air temperatures in the Mediterranean region are projected to *very likely* continue to increase more than the global average, together with an increase in frequency and intensity of hot extremes, increase of evapotranspiration *(high confidence)*, decrease in precipitation (*high confidence* for 4°C global warming level) depending on future reductions in greenhouse gas emissions. *(Figure SPM3)* {2.2}

C.1.1 Surface air temperatures in the Mediterranean region, relative to 1850–1900, are projected to increase by 2.1 [1.6 to 2.7] °C[6] over the period 2041–2060 and 2.2 [1.6 to 3] °C over the period 2081–2100 under the very low GHG emissions scenario, and by 2.2 [2.3 to 3.6] °C over 2041–2060, and 5.5 [4.2 to 6.8] °C over 2081–2100 under the very high GHG emissions scenario *(high confidence)*. Heat waves will increase both over land and sea *(high confidence)*. {2.2.1}

C.1.2 Precipitation will decrease over most of the Mediterranean and heavy rainfall will increase in some areas of the northern Mediterranean (*low confidence* for 1.5°C global warming level, *high confidence* for 4°C global warming level). Global warming will further increase the existing difference in intensity of precipitation and hydrological extremes between the northern and southern Mediterranean *(high confidence)*. The projected increase in dry spell length is larger in the southern Mediterranean than in the northern Mediterranean *(medium confidence)*. {2.2.2}

C.1.3 Future decreases in precipitation, associated with increased evapotranspiration will lead to droughts, with drier soils and a decline in runoff and coastal freshwater supply, to become more severe under moderate emission scenarios and strongly enhanced under severe emission scenarios *(high confidence)*. {2.2.6}

C.1.4 Compared to the end of the 20th century (1976–2005), the sea surface temperatures of the Mediterranean Sea are projected to increase by the mid-21st (2021–2050) century in the range of 0.6°C to 1.3°C and by the end of the 21st century (2071–2100) in the range of 2.7°C to 3.8°C under the very high GHG emissions scenario *(high confidence)*. The warming at the end of the century will be smaller (from 1.1°C to 2.1°C) under an intermediate scenario. Warming is expected to be stronger in summer than in winter *(medium confidence)* and associated with longer and more intense marine heat waves *(high confidence)*. {2.2.5}

C.1.5 Seawater acidification is projected to continue both offshore and at the coast *(virtually certain)*. It is projected that the pH will decrease between −0.25 and −0.46 units in Mediterranean surface waters by the end of the century compared to the pre-industrial era in very high GHG emissions scenarios *(medium confidence)*. {2.2.5}

C.1.6 The future change in sea surface salinity of the Mediterranean Sea remains largely uncertain with very *low confidence* on its sign of change. Any change will *likely* be spatially and temporally inhomogeneous due to the primary role of river and near-Atlantic freshwater inputs *(medium confidence)*. {2.2.5}

C.2 Mediterranean relative mean sea level is expected to continue to rise during the coming decades and centuries at a rate depending on the future emissions of greenhouse gases *(virtually certain)*. The increase in relative sea level will cause more frequent coastal floods covering larger coastal areas *(virtually certain)*. *(Figure SPM3)* {2.2.4, 2.2.7}

---

[6] In the report, unless stated otherwise, square brackets [x to y] are used to provide the assessed *very likely* range, or 90% interval.

C.2.1 Mediterranean mean sea level is projected to rise during the coming decades and centuries, *likely* reaching 0.15–0.33 m by mid-21st century, and 0.32–0.62 m under the very low greenhouse gas emissions scenario and 0.63–1.01 m under the very high greenhouse gas emissions scenario by the end of 21st century, relative to 1995–2014 *(medium confidence).* The process is irreversible at the scale of centuries to millennia *(high confidence).* The long-term knowledge of vertical land movements is restricted to a limited number of sites where geological or geodetic surveys have been carried out. {2.2.7, 2.2.8}

C.2.2 The frequency of an extreme sea level event that occurs once in 100 years is *likely* to increase by 10–30% and 22–65% by the mid and end of the 21st century under an intermediate and very high emissions scenario respectively *(high confidence).* {2.2.4}

C.3 Future pollution levels along Mediterranean coasts are expected to exhibit varying trends across regions and pollutants, depending on regulations, decreasing dependency, diminishing production and socioeconomic changes. The leakage of plastics into the sea will depend on the rate of plastic production, regulations and waste management *(high confidence). (Figure SPM3)* {2.4}

C.3.1 Nutrient fluxes in the coastal zone are expected to decrease in the north due to the implementation of European environmental regulations and to increase in the south if urban development and agricultural intensification continue at the present pace *(high confidence).* The current nutrient imbalance in coastal ecosystems, with increasing availability of nitrogen relative to phosphates, leading to exacerbated eutrophication problems, is expected to increase *(high confidence).* {2.4.1}

C.3.2 Concentrations of certain persistent organic pollutants (POPs), such as polychlorinated biphenyl (PCBs) and dichlorodiphenyltrichloroethane (DDT), will continue to decline in Mediterranean coastal areas due to regulations *(medium confidence).* Emerging pollutants such as pharmaceuticals and personal care products, are expected to increase due to socioeconomic changes and emerging industries to supply the demand *(medium confidence).* {2.4.3, 2.4.5}

C.3.3 The leakage of plastics into the sea depends on the rate of plastic production. By 2040 it is *likely* to double if annual plastic production continues to grow at a rate of 4% and waste management is not radically improved. Decreasing the production growth, implementing regulations limiting single-use plastic and improving waste management can reduce plastic leakage *(high confidence).* {2.4.4}

C.4 The Mediterranean is becoming increasingly colonised by non-indigenous species of tropical origin that are expanding their distribution ranges *(high confidence). (Figure SPM3)* {2.3.2}

C.5 Total coastal population of the Mediterranean is expected to grow faster than the inland population under most shared socioeconomic pathways, thus leading to increased exposure of the population and assets to coastal hazards *(high confidence).* This increase strongly depends on the socio-economic pathway and varies considerably between the geographic subregions. The northern Mediterranean may experience coastal population decline under some scenarios, while the highest increases in coastal population are expected in the Mediterranean Middle East and Maghreb countries *(medium confidence). (Figure SPM3)* {2.5.1}

D. Observed impacts and future risks

D.1 In general, the Mediterranean coastline is presently retreating, with large spatial variability and it will increase under the effect of climate change with consequences for ecosystems and the protection efficiency of present structures *(high confidence).* {3.2.2}

D.1.1 The most dramatic erosion is observed in river mouth areas, on coastal stretches around harbours and other coastal infrastructure as a result of decreased sediment supply and alteration of sediment fluxes caused by coastal structures *(very high confidence).* {3.2.2}

D.1.2 In the absence of adequate adaptation and protection measures, beaches will continuously erode during the coming decades, increasing risks of storm-induced damages and reducing the extension of areas for sun-and-beach tourism *(high confidence).* {3.2.2}

D.1.3 Coastal erosion will increase under the effect of climate change, as mean sea level rise will enhance erosion in combination with storms, aggravating a generalised shoreline retreat. In the future the projected median value of shoreline retreat for the Mediterranean with respect to 2010 is 17.5 [8.8 to 27.7] m and 23 [11.1 to 36.3] m by 2050 under the intermediate and very high greenhouse gas emissions scenarios, respectively, increasing to 40 [20.1 to 65.1] m and 65 [31.3 to 115.0] m respectively by 2100 *(medium confidence).* {3.2.2}

D.1.4 Coastal erosion will increase flooding and reduce the degree of protection provided by existing infrastructure along the coast, thereby increasing risk of storm-induced damages *(high confidence).* {3.2.2}

D.1.5 Coastal erosion will also lead to a loss of ecosystem services as coastal zone habitats will be affected, degraded and, eventually, disappear due to coastal squeeze *(medium confidence)*. {3.2.2}

D.2 Regional sea level rise will increase the risk of storm-related floods and also result in the permanent inundation of certain areas along the Mediterranean coasts. Climate change and growing urbanisation will further increase the risk of flash floods in some coastal areas *(medium confidence).* Risks caused by meteorological and seismic tsunamis will continue to be present *(high confidence). (Figure SPM4)* {3.2.3, 3.2.4}

D.2.1 In the Mediterranean, waterfronts, seaward parts of coastal settlements and low-lying areas are exposed to flood risk caused by waves during storms, which, in the absence of efficient adaptation/protection measures, will generally increase in the future because of mean sea level rise *(high confidence).* Future mean sea level rise will lead to an increased frequency and intensity of coastal floods *(high confidence).* {3.2.3}

D.2.2 Mean sea level rise will cause gradual and permanent inundation of low-lying unprotected areas in deltas and coastal plains, being locally often aggravated by subsidence, putting at risk natural and cultural values, and important agricultural activities *(high confidence).* {3.2.3}

D.2.3 Risks posed by flash floods are high in several coastal stretches of the Mediterranean because of exposed and vulnerable urban settlements, densely populated areas, local weather regimes, and topographic conditions. In the future, in the absence of efficient adaptation, flash flood risks are expected to increase in relation to the increase in the frequency of heavy rainfall events and population density in flood prone coastal areas (including France, Greece, Italy, Spain, Türkiye) *(medium confidence).* {3.2.3}

D.2.4 The Mediterranean coast is among the areas with the highest probability of compound flooding in comparison with European coasts due to the combined occurrence of heavy rainfall and high-water levels. The expected evolution of these events under climate change will be affected by the increase of both hazards, although with a large spatial variability in their occurrence and no clear trend regarding their intensity and frequency *(medium confidence).* {3.2.3}

D.2.5 The occurrence of meteotsunamis (tsunamis caused by meteorological events) is relatively frequent along some stretches of the Mediterranean coast (eastern Adriatic, Balearic Islands, strait of Sicily, Maltese Islands) with specific hotspots in some bays and inlets where resonance is favoured. They pose significant risks for Mediterranean coastal zones: Due to the small tidal ranges in the Mediterranean, coastal infrastructure is generally not adapted to avoid meteotsunami damages, and flooding is potentially more severe in the Mediterranean in comparison to other macro-tidal coasts of the world. {3.2.4}

D.2.6 Tsunamis produced by seismic events have caused severe damages and loss of lives in the past. Due to the high seismicity of the Mediterranean basin, the short travel times of tsunami waves to the coast from source areas and the concentration of population and assets along the coastal zone, tsunamis are a significant threat for the Mediterranean coastal zones despite their low frequency, with the eastern basin being the most affected. {3.2.4}

D.2.7 In the absence of effective adaptation policies in the Mediterranean region, up to 20 million people could be affected by permanent displacement due to sea-level rise by 2100. This exposure is about three times higher in the southern and eastern countries than in the northern countries *(low confidence).* {3.4.2}

D.3 Risks of water scarcity in the coastal areas of the Mediterranean are caused by the overall drying trend affecting the region, salinisation of coastal aquifers, increasing demand associated with population growth, irrigation, touristic use, industry and the energy sector. Risks of water scarcity are expected to increase in the future *(high confidence). (Figure SPM4)* {3.2.5}

D.3.1 Seawater intrusion in coastal aquifers affects a considerable part of the Mediterranean coast. In the future, salinisation of aquifers could further increase in the coastal areas affected by relative sea level rise *(high confidence).* {3.2.5}

D.3.2 Tourism and irrigated agriculture produce water demand peaks during summer. Increase in irrigation demand (driven by climate change and agricultural practices), the increase in population, particularly in the coastal areas of eastern and southern Mediterranean countries, and summer tourism are expected to lead to growing water demand in the future *(high confidence).* In the future, reduced precipitation and increased evapotranspiration will lead to a decline of runoff in the Mediterranean region and consequently affect the supply of fresh water to coastal areas *(high confidence).* {3.2.5}

D.3.3 Future degradation and reduction of the availability of conventional freshwater resources for the different uses is expected, especially in the southern and eastern Mediterranean *(high confidence).* {3.2.5}

D.4 Mediterranean coastal wetlands have significantly declined since the beginning of the 20th century. Coastal ecosystems and their services are at risk of further deterioration in the future. Risks can be further increased by changes in sediment supply, and industrial and urban development *(high confidence). (Figure SPM4)* {3.5}

D.4.1 Mediterranean coastal wetlands have experienced a substantial decline, losing approximately 50% of their area during the 20th century, due to a combination of erosion, extreme events, salt-water intrusion, and mainly human-induced pressures (such as expansion of irrigated agriculture), and urban, industrial and infrastructure development. They will be significantly affected by future changes in precipitation *(high confidence),* although with a high spatial variability. Sea level rise and coastal erosion will lead to further losses of coastal wetlands *(high confidence),* especially in areas where existing rigid inland boundaries limit the potential horizontal migration of wetlands. {3.5}

D.4.2 Degradation, regression and biodiversity loss, and, eventually, disappearance of ecosystem habitats will lead to an overall decline in ecosystem services relative to current conditions *(high confidence).* For the northern Mediterranean coast, the decline in services could reach around 6% of the present value by 2100 under the very high greenhouse gas emissions scenario, but with high spatial variability and the largest decline occurring in the north-eastern Mediterranean areas *(medium confidence).* A lack of studies prevents assessment for the rest of the Mediterranean coastline. {3.5.2}

D.4.3 The decrease in sediment supply, coupled with further industrial, urban and tourism development, can enhance the vulnerability of coastal sandy beaches, wetlands, and saltmarshes to sea level rise. {3.5.2}

D.5 In the Mediterranean Sea mass mortalities in coastal waters have been recently observed, they have been partially attributed to marine heat waves and are expected to increase in the future *(high confidence).* {3.2.7}

D.5.1 Mass mortality events in the Mediterranean Sea have been observed in recent decades, affecting corals, sponges, molluscs, bryozoans and echinoderms, and they have been attributed to marine heat waves and pathogen infections. Many Mediterranean coastal species are reaching their tolerance limits due to ocean warming and repeated marine heat waves *(high confidence).* {3.2.7}

D.5.2 The frequency and intensity of mass mortality events will *likely* increase in the future in parallel with rising marine heat waves *(high confidence).* {3.2.7}

D.5.3 Mortality risks are increased by the synergistic effects of warming and pollution *(medium confidence).* {3.2.6}

D.6 Alteration of species distribution and population have been observed, such as the presence of non-indigenous species and jellyfish blooms. {3.2.7}

D.6.1 Non-indigenous species affect indigenous species through predation, competition for resources and ecological niches, food web shifts and as vectors of pathogens or parasites. Non-indigenous species are producing a variety of ecological and socio-economic impacts on the Mediterranean, with examples of negative impacts on native biodiversity and coastal ecosystem services, mainly food provision *(high confidence).* {3.2.7}

D.6.2 Recent studies suggest an increase in the frequency of jellyfish blooms in the Mediterranean Sea, which has been linked to eutrophication and other human induced stressors, including anthropogenic warming *(medium confidence).* {2.3.3}

D.7 In the Mediterranean coastal region, climate change is expected to pose serious risks to important economic sectors such as summer beach tourism, agriculture, aquaculture and fisheries *(high confidence). (Figure SPM4)* {3.3}

D.7.1 Hot temperatures and heat waves are expected to reduce the traditional attractiveness of the Mediterranean beaches in the summer, while increasing suitability of spring and autumn seasons for beach tourism *(medium confidence).* The narrowing and eventual disappearance of beaches poses high risks for the sun-and-beach tourism sector, especially in urbanised areas where the coastal zone is limited by physical barriers, such as numerous coastal stretches in Cyprus, France, Greece, Italy, Malta and Spain, among other countries *(high confidence).* {3.3.1}

D.7.2 In the coastal areas of the Mediterranean, risks for agricultural productivity are posed by the overall loss of the quality and availability of water resources and the loss of agricultural land, caused by erosion and permanent submersion. In absence of adequate adaptation, agricultural land located in low-lying coastal areas, such as the plains of the Nile, Ebro and Po deltas, will be affected by the impacts of relative sea level rise *(high confidence).* {3.3.2}

D.7.3 Climate change is affecting the range and quantity of species available for commercial exploitation *(medium confidence)* and favouring the emergence of non-indigenous species *(medium confidence).* Mediterranean fisheries are overexploited, and the majority of stocks are declining *(high confidence).* {3.3.3}

D.8 Sea level rise is expected to put Mediterranean coastal structures, such as airports, transport networks, ports, and cultural heritage sites at risk *(high confidence).* {3.3.5, 3.4.1}

D.8.1 Three out of the world's 20 airports most at risk of coastal flooding due to sea level rise are located in the Mediterranean[7]. In several Mediterranean countries, roads and railways are located close to the shoreline and exposed to the risk of flooding and erosion. Multi-hazard conditions affecting Mediterranean ports are projected to significantly worsen due to climate change under a very high emission scenario. The absence of adequate adaptation will increase risks for operating Mediterranean ports, particularly in the southern Mediterranean. The extent of this increase will vary depending on local conditions, with port configuration being a crucial factor *(medium confidence).* {3.3.5}

D.8.2 Sea level rise is expected to reduce the effectiveness of protection provided to the coast by parallel breakwaters, due to increased overtopping. The extent of this impact will largely depend on the height of the structures *(high confidence).* Significant sea level rise will make the design and planned operativity of the current Venice defence systems inadequate *(medium confidence).* {3.3.5}

D.8.3 The large majority of Mediterranean UNESCO cultural World Heritage Sites in low elevation coastal zones are currently at risk of erosion and coastal flooding *(high confidence).* Coastal built heritage is *likely* to also be affected by slow cumulative deterioration processes, with an increase in the risk of decohesion due to salt crystallisation and mechanical stress *(very high confidence).* {3.4.1}

D.9 Diverse pollutants affect the coastal waters of the Mediterranean Sea with negative impacts on ecological systems, human health and economic sectors (aquaculture, fishing, and coastal tourism). The risks associated with coastal pollution are expected to increase as anthropogenic pressures in coastal zones continue to grow, exacerbated by the compounding effects of climate change, leading to cumulative and synergistic impacts *(medium confidence). (Figure SPM4)* {3.2.6, 3.2.7}

D.9.1 High nutrient fluxes from land sources cause eutrophication with adverse consequences, such as hypoxia or anoxia, episodes of massive mucilage formation and harmful algal blooms. Mucilage has been reported, particularly in highly productive and shallow water coastal areas of the Mediterranean. It reinforces hypoxic and anoxic conditions, negatively affecting benthic organisms and damaging tourism and fisheries. {3.2.6, 3.2.7}

D.9.2 Metals are accumulating in estuaries, wetlands, deltas, prodeltas and, more generally, in coastal and seafloor sediments with some having negative impacts on organisms (such as immunosuppression, impaired reproduction and development) even at minute concentration. They also accumulate in marine organisms throughout food webs (the bioaccumulation of mercury is a representative example). {3.2.6}

D.9.3 Pharmaceutical residuals and other emerging pollutants reach coastal waters through rivers and domestic effluents, where conventional processes are unable to treat them. These emerging pollutants present a risk of acute or chronic toxicity to aquatic organisms *(medium confidence).* {3.2.6}

D.9.4 High concentrations of plastics are a major risk for marine biodiversity. Coastal areas are generally hotspots for plastic ingestion and coastal species are at higher risk than open-sea species *(medium confidence).* Risks to human health are due to the ingestion and accumulation by commercially

---

[7] Ioannis Kapodistrias Intl in Greece, Pisa and Venice in Italy.

exploited seafood and spread through the trophic chain *(medium confidence).* {3.2.6}

D.9.5 Complex interactions between climate change impacts and pollutants in the coastal environment will become more frequent due to multiple stressors from both natural and anthropogenic sources *(medium confidence).* {3.2.6}

D.9.6 The occurrence of natural disasters and environmental degradation linked to pollution has multiple direct and indirect impacts on the health and well-being of coastal populations along the Mediterranean Basin. In the absence of effective adaptation, risks are expected to increase in the near future as climate change hazards and coastal populations are expected to increase *(high confidence).* {3.4.2}

E. Adaptation measures and solutions

E.1 Reducing risks posed by climate hazards has primarily included protection against coastal flooding, prevention of coastal erosion and conservation measures for coastal ecosystems. Both protection against coastal flooding and management of coastal erosion generally fail to properly consider future sea level rise, with risks of limited future effectiveness *(high confidence).* The effectiveness of conservation measures for coastal ecosystems strongly depends on the success of climate change mitigation and an increasing number of hard limits will be reached for every increment of global warming *(high confidence). (Figure SPM4)* {4.2.4}

CLIMATE AND ENVIRONMENTAL COASTAL RISKS IN THE MEDITERRANEAN & SUSTAINABLE DEVELOPMENT GOALS

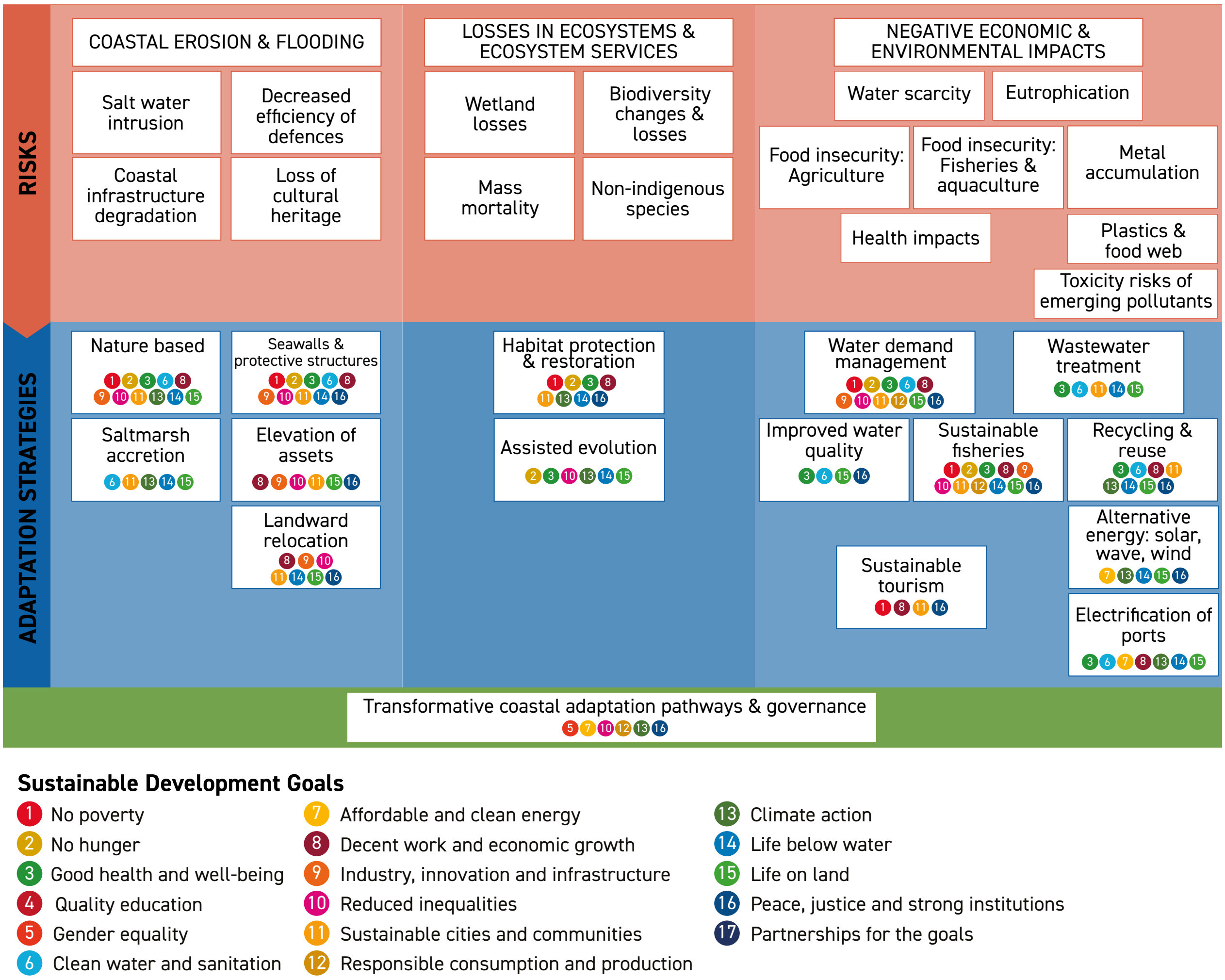


Figure SPM4 | Risks, adaptation and solution in the Mediterranean coastal zone and their links to the Sustainable Development Goals (SDGs).

E.1.1 Protection against coastal flooding, except for a few examples of relocation and nature-based solutions, typically relies on relatively high-cost engineering solutions, with negative effects on coastal landscape, biodiversity and ecosystems *(high confidence).* The lack of consideration of sea level rise in coastal flood-risk management is widespread and comes with the risk that during the 21st century, defence systems will reach soft limits, lock-ins and maladaptation *(high confidence).* {4.2.1}

E.1.2 Prevention of coastal erosion by engineering protection and artificial nourishment of beaches is becoming less efficient due to sediment scarcity *(medium confidence).* Nature-based solutions are increasingly discussed. They have economic and environmental advantages, but trade-offs with the use of beaches, and coastal resources limit the scale of their implementation *(high confidence).* Landward relocation with appropriate planning could represent a sustainable solution in some areas, especially when other adaptation measures are not viable. Along the European Mediterranean coastline, relocation is limited by the lack of space in low-lying coastal areas and by low social and current economic feasibility, but it might become economically viable in the long term *(medium confidence).* {4.2.2}

E.1.3 Current management of coastal erosion generally overlooks the risks posed by sea level rise *(high confidence).* Transparent communication and governance are essential for avoiding short-term interventions and maladaptation in the future *(medium confidence).* {4.2.2}

E.1.4 Autonomous adaptation of coastal ecosystems requires adequate conservation measures, such as habitat protection, limitation of human pressures, reduction of pollution, ensuring sufficient accommodation space and area-based conservation measures, which in the Mediterranean are too limited in scale and ambition to curb coastal ecosystem losses *(high confidence).* Active restoration remains too limited to support the recovery of habitats at relevant ecological scales, while coastal protection measures reduce and fragment habitats *(high confidence).* {4.2.3}

E.1.5 The efficiency of conservation measures strongly depends on the success of climate change mitigation, that is limiting warming climate change below 1.5°C with no or small overshoot *(medium confidence).* Adaptation limits of coastal terrestrial, freshwater and brackish water ecosystems will be reached above 3°C of global warming in the north-eastern Mediterranean and possibly earlier in the eastern and southern Mediterranean *(high confidence).* {4.2.3, 4.2.4}

E.1.6 Reducing the risk of possible conflicts and side-effects of some adaptation actions on other related sectors can be achieved through cross-sectoral adaptation strategies. Such strategies, if included in a regional "Mediterranean" framework, would enable cooperation and more effective cross-border measures to be undertaken. {4.2.3}

E.2 Mediterranean coastal waters are heavily influenced by pollution originating from numerous mainly land-based human activities such as industry, agriculture, urbanisation, and tourism. Actions to control pollution at its sources are generally more efficient than those treating it at endpoints *(medium confidence).* Actions to tackle pollution at a Mediterranean scale have not been implemented yet, and technical and decision-making challenges remain to be solved. *(Figure SPM4)* {4.3}

E.2.1 Management of pollution both at the sources and at the endpoints requires continued long-term monitoring, using an appropriate set of indicators and adaptive recovery management plans *(high confidence).* Actions aimed at the sources are more efficient, particularly in the case of point sources, as they are usually simpler to be implemented, long-lasting, easier to monitor, and cheaper, while they are more problematic in the case of dispersed sources and at endpoints *(medium confidence).* {4.3}

E.2.2 Strategies to reduce coastal pollution include use of municipal solid waste for the waste-to-energy industry, recycling and re-use of wastewater, sustainable farming practices and more efficient treatment of polluted water from farming activities and eco-remediation. {4.3.1, 4.3.2}

E.2.3 There is currently no consistent strategy approach to reduce plastic litter pollution at Mediterranean scale, as the gap between politics, science and society still complicates the co-design and implementation of effective mitigation measures. The effectiveness of solutions is further still limited by knowledge gaps, technical difficulties and economic costs *(medium confidence).* {4.3.4}

E.2.4 The implementation of pollution management strategies differs among Mediterranean countries. In order to ensure effective decision-making, coordination among parties, improved spatial consistency of information on litter distribution, and awareness-raising measures are fundamental. {4.3.5}

E.2.5 Waste prevention through law-enforcement, appropriate waste management and monitoring the effectiveness of implemented actions (such as those included in the European Marine Strategy Framework Directive) are important components to achieving Good Environmental Status. {4.3.4}

E.3 Although the presence of non-indigenous species is observed throughout the Mediterranean region, solutions have been rarely attempted, with few successful examples. Management of non-indigenous species are based on actions at regional levels: eradication initiatives; efforts for their commercial exploitation; protection of indigenous species by providing suitable habitat, protected areas, and ecological connectivity. {4.4}

E.4 Adaptation needs to water shortages vary significantly across sub-regions, depending on the hydrogeological and coastal water management context. Adaptation to reduced water availability is taking place in Mediterranean coastal areas *(high confidence).* These adaptation options consist in increasing water supply, improving water quality, supporting measures and governance, and to a lesser extent reducing water demand. *(Figure SPM4)* {4.2.4}

E.4.1 Observed adaptation to reduced water availability is often based on increasing water supply based on diversified strategies (water diversion and transfers, diversification of resources, surface reservoirs, desalination), which, though effective, pose social, environmental, and economic challenges, and can reach hard limits *(high confidence).* {4.2.4}

E.4.2 Water demand management measures, although an important component to limiting future risks of water scarcity, are not widely used *(high confidence).* Sustainable water demand can be achieved by improving irrigation practices, changing agricultural practices, improving urban water management, through economic and financial incentives, and regulating distribution *(high confidence).* {4.2.4}

E.4.3 Nature-based solutions, such as favouring saltmarsh accretion to reduce surface saltwater inflow into aquifers and estuaries have limitations in terms of feasibility and efficiency for high rates of sea level rise *(high confidence).* {4.2.4}

E.4.4 A transformation of the water-food-energy nexus, while taking into account the ecosystem, can bring substantial co-benefits to the reduction of water shortage risks, such as improved human health, aquaculture easing and healthier terrestrial and freshwater ecosystems *(high confidence).* {4.3}

E.5 The engagement of scientists with policymakers, stakeholders, and citizens is a key factor to removing barriers (including lack of understanding and trust) and can be particularly beneficial during the planning process. Turning stakeholders into partners significantly increases the potential of successfully implementing solutions and adaptation measures *(high confidence).* {4.7}

E.5.1 Coastal adaptation management and planning processes provide unique opportunities for the establishment of permanent frameworks for science-policy-community interaction. Such frameworks require sufficient resources, are based on transparency and are the key for building partnerships and trust. Plans that are co-created by science-policy-community groups strongly increase their chances for successful implementation *(high confidence).* {4.7.3}

F. Recent developments and sustainable development pathways

F.1 Current actions towards solutions to environmental problems, adaptation to climate change and its mitigation are insufficient to attain the Sustainable Development Goals (SDGs) ensuring the well-being of people and the sustainability of resources in the Mediterranean coastal zone *(medium confidence). (Figure SPM4)* {5.2, 5.3}

F.1.1 Climate change, in combination with other drivers such as urbanisation, rural exodus, and population growth, are a threat to the vital services provided by Mediterranean marine and coastal ecosystems *(high confidence).* {5.4.5}

F.1.2 Further research is needed to establish the risks posed by the implementation of renewable energy projects (wind, solar and wave energies, hybrid systems) to the unique biodiversity of Mediterranean coastal ecosystems *(medium confidence).* {5.3}

F.1.3 The most vulnerable people in society - such as the elderly, migrants, refugees, internally displaced individuals, women, children and low-income earners - who are exposed to climate hazards, such as heat waves and flooding, among others, are in many cases not adequately engaged in the policy-making processes nor adequately considered in policy measures, to ensure efficient and just transition to changing environment and climate *(medium confidence).* {5.4}

F.1.4 Crucial socioeconomic sectors, such as tourism, ports and maritime transport, construction and real estate, contribute to economic development and employment, but are largely based on extractive models of development, insufficiently embracing circularity and sustainable development practices *(medium confidence).* {5.3}

F.1.5 The current share of carbon emissions of the Mediterranean countries amounts to no more than 6 percent of global emissions, with northern Mediterranean countries contributing the largest proportion. While greenhouse gas emissions in northern Mediterranean countries have been systematically decreasing since 2005, they have been continuously increasing in southern and eastern Mediterranean countries since the 1960s, mainly driven by economic and population growth and do not show a promising path in their reduction given the expected increase in energy demand in the next few decades *(high confidence).* {5.2.1}

F.1.6 Among renewable energy sources in the Mediterranean coastal zone, offshore wind energy is a feasible viable option while wave and thermal gradient energies are still in the early stages *(medium confidence).* Despite some progress in promoting the transition from fossil fuels to renewable and clean energy sources and efforts to support conservation and restoration of blue carbon pools (such as coastal ecosystems), sustainable development pathways are not progressing sufficiently to achieve net zero targets by the mid-21st century *(high confidence).* {5.3}

F.1.7 Low carbon energy pathways in coastal economies are essential for sustainable local and regional economic growth and stability *(medium confidence).* In the quest for decarbonisation, alternative fuels and energy sources such as biofuels, synthetic fuels, hydrogen, and batteries are emerging in the Mediterranean. Transition to more economically, socially and environmentally sustainable maritime transport would result in relatively lower carbon emissions per tonne transported compared to land and air transport *(low confidence).* {5.3.1}

F.2 Without transformative actions across all sectors, systems, and scales climate change risks will be exacerbated and the UN Sustainable Development Goals will not be met *(high confidence).* A mix of legal, policy and economic instruments, and behavioural nudges, are available for local, national, and regional authorities to promote effective climate resilient sustainable development pathways in the Mediterranean coastal zone. Properly identifying vulnerabilities related to human activities and climate change impacts, assessing opportunities to reduce risks to the affected communities and ecosystems, and adopting actions consistent with the Sustainable Development Goals are fundamental for pursuing these goals *(high confidence). (Figure SPM4)* {5.3, 5.4}

F.2.1 Carbon neutrality by 2050 can only be reached by ensuring more political and economic stability, and implementing circular and sustainable development models, especially in southern and eastern Mediterranean countries, in order to decouple energy consumption from economic growth *(high confidence).* {5.2.2}

F.2.2 There is a consistent potential for climate change mitigation and adaptation through effective conservation and restoration of blue carbon ecosystems including seagrass meadows, coastal wetlands, salt marshes and coastal terrestrial ecosystems (including coastal dunes). The carbon sequestration capacity of coastal wetlands is about 10 times that of terrestrial ecosystems, but they are not sufficiently protected *(high confidence).* {5.2.2}

F.2.3 An effective implementation of the sustainable blue economy is a powerful way to protect and transform Mediterranean marine and coastal areas, fostering resources for local, inclusive, sustainable and resilient development *(high confidence).* Ensuring continuous monitoring and assessment of coastal ecosystems and their valuable services can support the adoption of dynamic adaptive strategies *(medium confidence).* {5.2.2}

F.2.4 Coastal tourism is a strong economic driver and as such has a key role in fostering sustainable development pathways, especially by shifting from generally wasteful and overconsumption practices to more circular and sustainable ones *(medium confidence).* Sustainable tourism, which promotes local communities and conserves natural resources, is endorsed by international organisations and programs. Ecotourism models can use alternative policy tools including green taxes and eco-labelling schemes *(high confidence).* Additionally, the negative impacts of tourist cruises on air quality can be reduced by electrification of ports and controlling the emission of pollutants *(medium confidence).* {5.3.1, 5.3.2}

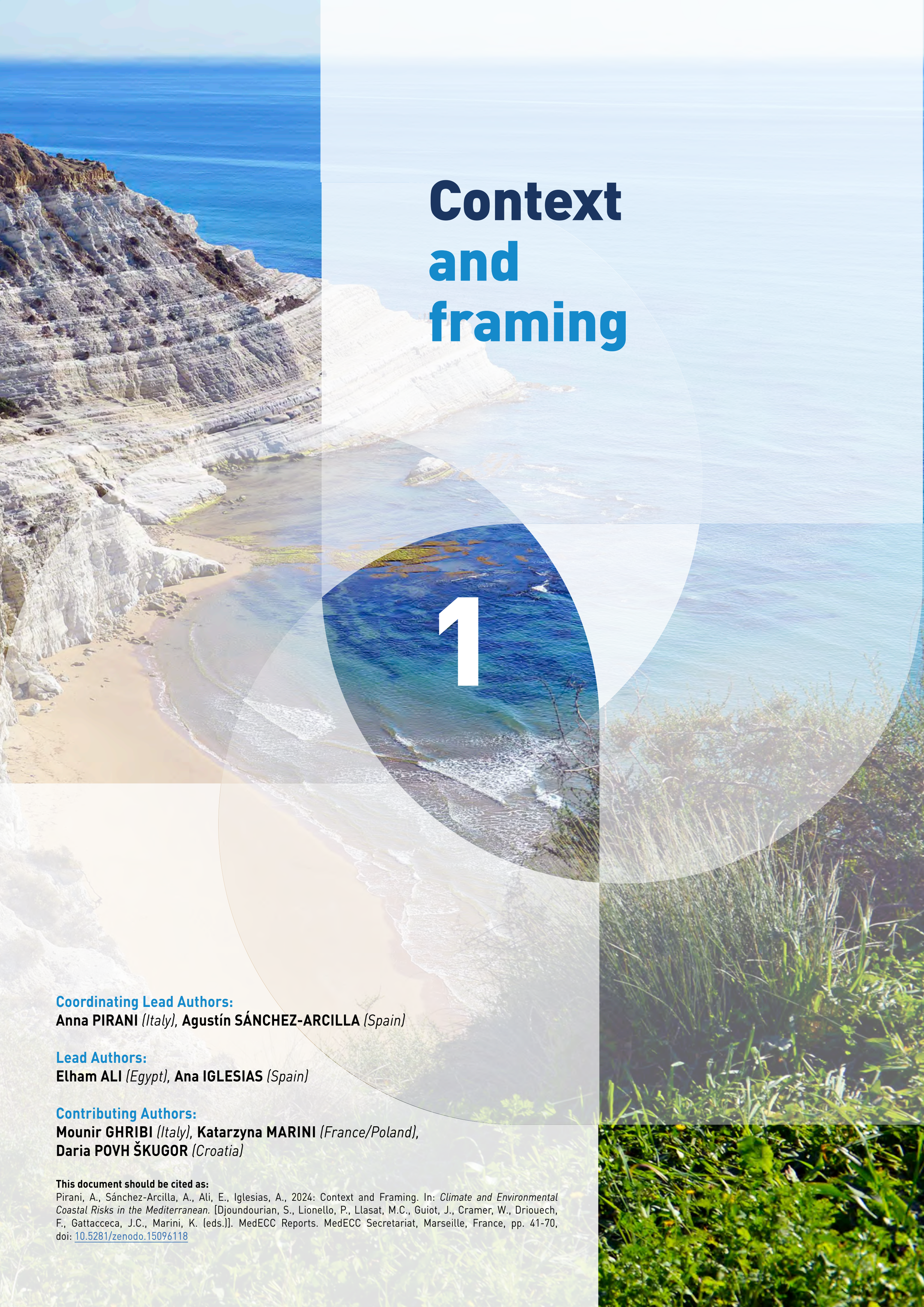
F.2.5 Actions towards reducing the overexploitation of fish stocks and the resulting negative impacts, particularly on small-scale fishers, include their meaningful participation in the co-management of the sector, the implementation of best practices to maximise the value of catches and the establishment of vertically-integrated distribution channels especially at local level *(high confidence).* {5.3.1}

F.3 Social inequalities, access to basic service, and gender-based inequalities are issues of concern in the Mediterranean region and in its high urbanised coastal zone as they act as a barrier to the implementation of sustainable development pathways *(high confidence).* {5.4}

F.3.1 Existing social inequalities across the Mediterranean Basin act as a further barrier to climate change adaptation and sustainable development pathways. A careful analysis of distributional effects of policies, adaptation actions and development programmes is fundamental to avoiding the risk of negatively impacting low-income earners *(high confidence).* {5.4.1}

F.3.2 Social infrastructure has a positive impact on social cohesion, by ensuring equal access to basic services (such as healthcare and education) across cities and regions. However existing inequalities within and among Mediterranean countries can undermine social cohesion *(high confidence).* {5.4.2}

F.3.3 In the Mediterranean countries where gender-based inequality is high, developing transformative coastal adaptation pathways by empowering women's participation in decision-making and support programmes, contributes to the achievement of SDG5 – Gender equality *(high confidence).* {5.4.4}



Context and framing

1

Coordinating Lead Authors:
Anna PIRANI *(Italy)*, **Agustín SÁNCHEZ-ARCILLA** *(Spain)*

Lead Authors:
Elham ALI *(Egypt)*, **Ana IGLESIAS** *(Spain)*

Contributing Authors:
Mounir GHRIBI *(Italy)*, **Katarzyna MARINI** *(France/Poland)*,
Daria POVH ŠKUGOR *(Croatia)*

This document should be cited as:
Pirani, A., Sánchez-Arcilla, A., Ali, E., Iglesias, A., 2024: Context and Framing. In: *Climate and Environmental Coastal Risks in the Mediterranean.* [Djoundourian, S., Lionello, P., Llasat, M.C., Guiot, J., Cramer, W., Driouech, F., Gattacceca, J.C., Marini, K. (eds.)]. MedECC Reports. MedECC Secretariat, Marseille, France, pp. 41-70, doi: 10.5281/zenodo.15096118

1

Chapter 1
Context and framing

Executive Summary

The Mediterranean is often referred to as a 'hotspot' of climate and environmental change given the high exposure and vulnerability of human societies and ecosystems and interconnected risks in this region (MedECC 2020a; Ali et al. 2022). A third of the Mediterranean population lives close to the sea and depends on infrastructure developed within the coastal zone. Policies to manage coastal risks and adaptation strategies in the context of sustainable development are therefore important for the whole region. Policy development together with regional cooperation support greater integration of knowledge, applied to more sustainable and integrated Coastal Zone Management and its proper communication.

- Risk assessments for Mediterranean coastal zones address the specific features of climate, variability and extremes, and the often narrow and over-pressured coastal zones of the Mediterranean Basin. Coastal risk levels, estimated with explicit treatment of uncertainties can inform adaptation pathways and support coastal sustainability decisions. Coastal hazards, vulnerabilities, and exposure are assessed together with climate and environmental management scenarios. This combined information provides useful support for a transition towards risk reduction, building long-term resilience and sustainability in coastal governance, policies, as well as social perception.

- Adaptation pathways provide a sequenced set of actions to sustain coastal zones and control risk levels, including change stations (indicating shift in adaptation pathways) and tipping points (indicating a threshold in adaptation pathways) to guide coastal decisions. The preparation of adaptation pathways favours objective discussions among stakeholders to co-decide preferred adaptation options and deadlines for their implementation, which in turn facilitates the generation of sufficient funding and supportive policies.

- Coastal risks have consequences for biophysical values and social activities. Understanding how risks are distributed within and among communities can inform adaptation policy development. A value-based approach guides the understanding between nature and society, placing the social and cultural values in context within the region.

- Adaptation plans designed by local and regional administrations typically focus on the need to protect communities, and minimise impacts on the natural environment, such as ensuring ecosystem resilience. Including ethical considerations would lead to informed and more socially- and ecosystems-oriented adaptation policies.

1

1.1 Introduction

The First Mediterranean Assessment Report (MAR1) on the current conditions and expected risks of climate and environmental change in the Mediterranean Basin was published on 17 November 2020 by the network of Mediterranean Experts on Climate and environmental Change (MedECC) (MedECC 2020a). It was prepared by 190 scientists from 25 countries. To produce this report, more than 3800 articles and reports in the scientific literature were assessed. The overarching goal for the development of MAR1 was to cover all major risks associated with environmental change as comprehensively as possible, regarding the major drivers of risk, the major systems impacted and as much as possible the sub-regions of the Mediterranean Basin. During this assessment, several important issues emerged that require deeper analysis, often associated with progress published in new scientific studies. It was therefore proposed that the MedECC community, and the approach developed for MAR1, could be used to produce a Special Report, during the 2021–2024 period, addressing coastal risks in the Mediterranean region. The coastal zone is generally defined as the interface between land and sea including the land area affected by marine processes, and the part of the sea affected by terrestrial processes, considering relevant biophysical and socioeconomic criteria, well-illustrated by low lying deltas subject to marine flooding, erosion and salinisation.

The Special Report on Climate and Environmental Coastal Risks in the Mediterranean is structured with an opening introductory chapter *(Chapter 1)* that provides readers with the context, background and key dimensions, particularly the risk framework, of this assessment. The report has three central chapters: the first assesses the drivers of coastal risks in the Mediterranean and their interactions *(Chapter 2)*; the second addresses coastal climate change and environmental impacts and risks for human and natural systems in the Mediterranean *(Chapter 3),* and the third explores the existing and prospective responses and management approaches to managing climate change and environmental risks, the existing policy-research interface, and presents best practices across the Mediterranean region *(Chapter 4).* The final chapter *(Chapter 5)* summarises the available knowledge about climate resilient sustainable development pathways for Mediterranean coasts, building on the outcomes of *Chapters 2* to *4*.

This introductory chapter sets the context for the Special Report in terms of the policy, natural environment and societal context of the report, focusing on the general risk framing, as well as key definitions, including context-specific nuances that are relevant across the report. It identifies what is assessed in the report, building on recent developments, and considering the latest relevant international assessments both at global scale and with a special focus on the Mediterranean. The introduction establishes a common assessment framework to facilitate the communication and synthesis of the results for stakeholders and users more broadly.

1.1.1 Mediterranean coastal risks

As explained above, the Mediterranean is often considered as a 'hotspot' of climate and environmental change, with a third of the Mediterranean population (around 150 million people) living 'close' to a dynamic shoreline (e.g. public domain zones with a width of a few to hundreds of metres) or in a low elevation coastal zone (e.g. below 10 m with respect to sea level). This population depends on infrastructure developed within the coastal zone and is therefore significantly affected by marine drivers. As assessed in the MAR1 report (MedECC 2020a), 40% of Mediterranean coastal areas are built-up or otherwise modified, often rendering them particularly vulnerable to: (1) coastal flooding and erosion, caused by sea level rise in combination with extreme climate events and reduced riverine solid transport producing sediment starvation in deltas and estuaries; (2) infiltration of seawater into coastal aquifers (seawater intrusion); (3) general degradation of coastal habitats, including wetlands, seabed meadows and agricultural systems; (4) coastal squeeze and loss of water and sediment quality; and (5) cumulative pollution effects at selected sites, whose concentration of human and economic activities has resulted in increasing degradation of coastal ecosystems. The combined result is a disturbance in sediment supply and exchange between the different compartments of coastal systems, aggravated by additional environmental disturbances due to salinisation, pollution, urbanisation, and lack of accommodation space (Wolff et al. 2020).

Mean sea level in the Mediterranean Basin has risen by 1.4 mm yr^{-1} during the 20th century and it has accelerated to 2.8 mm yr^{-1} recently (1993–2018), with sea level rise expected to continue accelerating in the Mediterranean with regional differences. This rise will reach the expected global rate of 43–84 cm above current levels by 2100, but with a significant risk of exceeding 1 m in the case of further ice-sheet destabilisation in Antarctica (MedECC 2020a). Sea level rise will intensify most coastal risks through the increase in frequency and intensity of coastal floods and erosion events. Until 2100, coastal flood risks, which are mainly of marine origin but are compounded in river mouth areas by combined marine-riverine flooding, may increase by more than 50% and the erosion risk by more than 10% across the Mediterranean region (Reimann et al. 2018). Damaging flash floods are expected to increase in many countries including France, Italy, and Spain, mainly affecting coastal areas and river mouth areas where population and urban settlements are growing in flood-prone areas, becoming more frequent and/or intense due to climate change and land surface sealing by urbanisation. Important challenges to groundwater quality in coastal areas are expected to arise from saltwater intrusion driven by enhanced extraction of coastal groundwater aquifers and sea level rise.

Reduced precipitation and prolonged droughts will reduce the water discharge and sediment flow of Mediterranean rivers and catchments, leading to the risk of land loss in estuarine river mouths and deltas. The agricultural sector will be affected by direct impact (e.g. due to salinisation) or loss (e.g. due to eroded land) in agricultural areas within coastal zones, defined considering biophysical and socioeconomic criteria, as explained above. Coastal zones feature significant increases in salinity due to sea-level rise and decreasing freshwater availability, progressive sediment starvation due to river regulation, reduced catchment basin erosion and dam barriers, and enhanced flooding due to relative sea level rise (eustatic rise plus subsidence) that affect deltas and estuaries. The impacts are more severe on the less mobile and resilient species, although mitigated by improved irrigation practices, use of recycled waters or more nature-based solutions for coastal areas.

Coastal erosion due to sea level rise and urban development will also *likely* affect tourism. The effect of sea level rise, together with changes in storm features are *likely* to seriously impact port operations, slowing down trade operations and productivity levels. Parts of the rich Mediterranean cultural heritage, notably the World Heritage Sites (WHS) implemented by the United Nations Educational, Scientific and Cultural Organization (UNESCO), are threatened directly by sea level rise, energetic storm events (e.g. medicanes), concentrated precipitation (e.g. Mediterranean flash floods) and other aspects of environmental change (Ribas et al. 2020; Sarkar et al. 2022).

Proactive adaptation to these hazards is essential for maintaining functioning coastal zones. Coastal adaptation practices can be classified into the following broad categories: protect, accommodate, advance, and retreat. Nature-based protection solutions, such as beach and shore nourishment, dune or wetland restoration, reforestation in upstream areas, and adequate agricultural practices to retain water, present an implementation gap despite recent advances in techniques and policies.

These practices, supported by advanced information such as from Early Warning Systems (EWSs), contribute to reducing flood fatalities and preparing societies to live with natural hazards. The MAR1 report assessed multiple risks faced in the Mediterranean region, defined as a ‘climate change hotspot’ due to the interconnected combination of hazards with high exposure and vulnerability. The report will compile new information and thereby update the assessment of MAR1 about coastal risks and identify potential for adaptation and risk reduction.

This report will inform Mediterranean policies on the development of an overarching framework to address the United Nations (UN) Sustainable Development Goals (SDGs) of particular importance to the whole Mediterranean region, such as combating climate change, increasing food security, managing natural resources, reforming health systems, creating opportunities for social inclusion, economic prosperity, and human equality or reducing risks of geopolitical instability. Science-policy dialogue can support this framing together with a multi-stakeholder approach, strengthened research cooperation mechanisms, and institutional partnerships, together in a shared ownership approach for the benefit of our Mediterranean (Mare

Nostrum). By recognising the value of countries' specificities as a strength for the region, there is the opportunity for a cultural transformation to create a proud community sharing the Mediterranean Sea as a common value.

1.1.2 The science-policy context

The Mediterranean has seen the development of various initiatives and activities that seek to impact policymaking by introducing a more systematic approach. Since 1975, Mediterranean countries have established an institutional framework for cooperation in addressing marine and coastal environmental degradation — Mediterranean Action Plan (MAP), under the auspices of the Regional Seas Programme of the UN Environment Programme (UNEP). In 1976, in Barcelona (Spain), a framework convention dedicated to the Protection of the Mediterranean Sea Against Pollution was adopted (Barcelona Convention)[8]. Other initiatives followed, such as the BLUEMED initiative and its Strategic Research and Innovation Agenda (SRIA)[9]; the EU COST Action on 'Ocean Governance for Sustainability'[10]; the EU COST Action on 'Unifying Approaches to Marine Connectivity for improved Resource Management for the Seas (SEA-UNICORN)'[11]; the UN decade of ocean science for sustainable development and various training on the science-society-policy interface in the Mediterranean promoted by UNESCO[12]; the Union for the Mediterranean (UfM)[13] and other actors. At a national level, various Mediterranean countries are implementing national adaptation plans. All these policy developments and regional cooperation initiatives are supported now by the EU Green Deal (EC 2019), which provides an important policy piece for the Mediterranean combining climate adaptation, biodiversity and zero pollution ambitions. This new policy framework should be applied for synergies with other initiatives such as the UNEP/MAP Barcelona Convention Ecosystem Approach[14] and the relevant EU Directives, aiming to achieve and maintain Good Environmental Status (GES) for Mediterranean Sea and coastal areas linked to more sustainable and integrated Coastal Zone Management. Therefore, the proposed thrust to support a new generation of policymakers through dedicated capacity building, timely science advice on policy and fostering dialogue within the knowledge triangle (academia-society-policy).

The UfM's policy dimension is structured around regional dialogue platforms involving representatives from governmental institutions and experts, regional and international organisations, local authorities, civil society, the private sector, and financial institutions. The UfM is also advancing regional and sub-regional cooperation by supporting integration and partnerships within shared objectives, including strengthening cooperation on blue economy and maritime governance, and facilitating the transition to a sustainable blue economy.

In 2008, fifteen Mediterranean countries signed the 7th Protocol of the Barcelona Convention, Protocol on Integrated Coastal Zone Management for the Mediterranean.[15,16] For the past six years, the countries have been negotiating the text of this Protocol, which is still innovative in many aspects. Its flagship article, Article 8, is the first international legal instrument that lays down the requirement for use of coastal setback zones, a buffer area where certain or all types of development ar6e prohibited or significantly restricted. It identifies a setback zone of a minimum 100 m from the shoreline as an agreed measure to protect coastal settlements and infrastructure from the negative impacts of coastal processes, including in particular, climate change

---

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

[9] https://www.bluemed-initiative.eu/bluemed-initiative/

[10] https://www.cost.eu/actions/CA15217/

[11] https://www.cost.eu/actions/CA19107/

[12] https://www.unesco.org/en/decades/ocean-decade

[13] https://ufmsecretariat.org/

[14] https://www.unep.org/unepmap/what-we-do/ecosystem-approach

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

[16] In 2023, the Member States of the Barcelona Convention are: Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, the European Union (EU), Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, Syria, Tunisia, and Türkiye.

consequences. Since 2008, this protocol has been ratified by twelve Mediterranean countries and the EU.[17]

The MedECC was launched in 2015 with the objective to assess the available scientific knowledge on climate and environmental change and associated risks in the Mediterranean Basin to render it accessible to policymakers, stakeholders and citizens. Interactions between MedECC and decision-makers and stakeholders are developed through a science-policy interface built mainly on close collaboration with UNEP/MAP, its Regional Activity Centre Plan Bleu, and the UfM. The MAR1 (MedECC 2020a) was an important step to further develop science-policy dialogue in the Mediterranean. During the second UfM Ministerial Meeting on Environment and Climate Action held in October 2021 in Cairo (Egypt), the 42 Ministers recognised in their declaration the Summary for Policymakers (SPM) of MAR1 (MedECC 2020b) 'as an important input of the scientific community to inform future climate and environment actions in the region' (UfM 2021, pp. 1-2). During the 22nd meeting of the Contracting Parties to the Barcelona Convention COP 22 (December 2021, Antalya, Türkiye), the SPM was endorsed by the Contracting Parties (UNEP/MAP 2021b) and reflected in the Antalya Ministerial Declaration (UNEP/MAP 2021a).

1.1.3 The Mediterranean coastal region

The land-sea coastal border has been defined above, using objective and subjective criteria for the coastal zone boundaries, although these criteria often present variable levels of uncertainty or fuzziness. Depending on the technical, economic or legal implications (e.g. public domain coastal zone) the extent of the coastal border may vary significantly and the variation of these borders with time (e.g. with sea level rise or with background erosion) is seldom explicitly considered in coastal management.

Both the land boundary and the sea boundary of this coastal zone are normally associated with gradients, illustrated by the urbanisation or geomorphological characteristics of the coastal land zone or by the dominance of nearshore and wave breaking processes for the ocean coastal zone. With the advent of new satellite data, providing spatially structured information, new definitions have started to appear such as the characterisation of the coastal zone sea boundary in terms of geological spatial gradients and variability (Sánchez-Arcilla et al. 2019). These definitions contrast with approaches for the land coastal zone, which define the coastal boundary in terms of elevation or width (e.g. coastal zone as a low elevation swathe).

In the Mediterranean, the land boundary can often be defined by mountain chains (land border) and narrow continental shelves (sea border), leading to different coastal zones depending on the application purpose. From a risk assessment standpoint, land and sea coastal zones should be considered as a single system, where the land and water parts interact at different scales. In summary, coastal zones, for risk assessments, should:

- Explicitly define land, sea, and lateral boundaries, considering the applicable European and national legislation;
- Address how these boundaries vary with time, considering the continuous land shifting of the public domain land-sea border due to sea level rise compounded by subsidence;
- Discuss the uncertainty in defining these boundaries, notably due to meteo-oceanographic variability and the difficulties in establishing a rigid delineation for a naturally dynamic boundary.

The following is a high-level summary of the aspects of the Mediterranean coastal system assessed, including cross-references to chapters in the report where the related detailed assessment is presented.

The Mediterranean coastal zone is characterised by high exposure to erosion and flooding due to cities and infrastructure being built close to the shoreline, in horizontal or vertical distance as defined above, within one of the most vulnerable regions to climate change (MedECC 2020a). Such closeness and the

---

[17] See the UN Glossary of terms relating to Treaty actions for more details on signature and ratification. https://treaties.un.org/Pages/Overview.aspx?path=overview/glossary/page1_en.xml

features of Mediterranean weather, associated with micro-tidal ranges, flash floods and short-duration wave storms *(Chapter 2)* also increase coastal pollution and environmental degradation, which make Mediterranean coasts highly vulnerable to climate change impacts *(Chapter 3)* due to the high concentration of populations, maritime traffic, infrastructure (ports, coastal and offshore), cultural values and ecosystems in a narrow coastal fringe.

High population pressure and coastal squeeze result in high risks for populations, the economy and cultural heritage that will increase with sea level rise and increasing temperatures (air and water) due to global warming. This includes negative impacts of population growth, coastal urbanisation, coastal fisheries and agriculture, as well as coastal tourism, which is particularly relevant for Mediterranean coasts *(Chapters 2* and *3).*

Weather patterns are highly variable, with rapid development of precipitation (e.g. flash floods) and wave storms (e.g. medicanes). Another Mediterranean specificity is sharp gradients in chemical water properties, illustrated by offshore oligotrophic conditions and high concentrations of nutrients, plastics, and emerging contaminants near the coast due to socioeconomic activities *(Chapter 2)*, particularly near river mouths, coastal cities, and port domains (Samper et al. 2022).

Rich coastal geodiversity, with sharp gradients in topography (e.g. mountain chains with river valley openings that condition weather patterns) and bathymetry (e.g. narrow continental shelves with submarine canyons) modulate meteo-oceanographic drivers and affect the impact of geohazards *(Chapter 2).*

Important differences in institutional capacity, social perception, and socioeconomic commitment to sustain coastal zones appear among different Mediterranean countries. In spite of this diversity in socioeconomic and institutional conditions *(Chapter 4)*, there is a need for common actions within sustainable adaptation pathways *(Chapter 5).*

Box 1.1

Core concepts

Definitions of key terms, required for coordinated interpretation of coming chapters, as used in the report *(Source: IPCC 2022a)*

- **Scenarios**
A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g. rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts but are used to provide a view of the implications of developments and actions.

- **Risk**
The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems.
In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those affecting lives, livelihoods, health and well-being, economic, social, and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species.
In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure, and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socio-economic changes and human decision-making. In the context of climate change responses, risks result from the potential of such responses not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the SDGs. Risks can arise, for example, from uncertainty in the implementation, effectiveness or outcomes of climate policy, climate-related investments, technology development or adoption, and system transitions.

- **Adaptation**
In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.

- **Adaptation pathways**
A series of adaptation choices involving trade-offs between short-term and long-term goals and values. These are processes of deliberation to identify solutions that are meaningful to people in the context of their daily lives and to avoid potential maladaptation.

- **Resilience**
The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation.

- **Climate resilient development pathways**
Trajectories that strengthen sustainable development and efforts to eradicate poverty and reduce inequalities while promoting fair and cross-scalar adaptation to and resilience in a changing climate. They raise the ethics, equity and feasibility aspects of the deep societal transformation needed to drastically reduce emissions to limit global warming (e.g. to well below 2°C) and achieve desirable and liveable futures and well-being for all.

- **Governance**
The structures, processes, and actions through which private and public actors interact to address societal goals. This includes formal and informal institutions and the associated standards, rules, laws, and procedures for deciding, managing, implementing and monitoring policies and measures at any geographic or political scale, from global to local.

- **Social justice**
Just or fair relations within society that seek to address the distribution of wealth, access to resources, opportunity, and support according to principles of justice and fairness.

- **Climate justice**
Links development and human rights to achieve a human-centred approach to addressing climate change, safeguarding the rights of the most vulnerable people and sharing the burdens and benefits of climate change and its impacts equitably and fairly.

- **Equity**
The principle of being fair and impartial, and a basis for understanding how the impacts and responses to climate change, including costs and benefits, are distributed in and by society in more or less equal ways. Often aligned with ideas of equality, fairness and justice and applied with respect to equity in the responsibility for, and distribution of, climate impacts and policies across society, generations, and gender, and in the sense of who participates and controls the processes of decision-making.

1.2 Climate and environmental change and impacts in the Mediterranean region

This section introduces the Mediterranean coastal zone characteristics that are assessed in the report and the climate change and environmental context of the Mediterranean (latest findings from MAR1, MedECC 2020a) and the sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC 2021; 2022b).

1.2.1 Observed and future climate change

The latest IPCC assessment (AR6) has concluded that human-caused global warming for the period 2010–2019 compared to the period 1850–1900 has reached 1.07°C (0.8°C to 1.3°C *likely*[18] range)[19] and that it is unequivocal that human influence has warmed all parts of the climate system – the land, ocean, and atmosphere (IPCC 2021). As a result, changes in climate conditions that affect society and ecosystems, referred to as climate impact-drivers, are occurring in all regions of the world in multiple and concurrent ways and are projected to increase in the future with every increment of global warming. Climate information can contribute to the assessment of future risks and planning for adaptation at regional scales considering the interplay between human-caused climate change, natural variability of the climate system and information on impacts, vulnerability, and exposure.

The Mediterranean region has experienced increased mean and extreme temperatures compared to the pre-industrial period that cannot be explained in the absence of human influence. Warming is projected to increase at rates that are greater than the global average. By how much will depend on the level of future mitigation of greenhouse gas emissions, as summarised in *Table 1.1*. With every increment of global warming, the Mediterranean is expected to experience increased and concurrent climate impact-drivers, generally hazards (temperature extremes, increase in droughts and aridity, decrease in precipitation, increase in fire weather, mean and extreme sea levels, and decrease in wind speed) that can lead to impacts on society and ecosystems. *Figure 1.1* shows projected changes in climate impact drivers for a level of global warming of 1.5°C and 3°C — mean, and extreme temperatures, total precipitation and maximum 1-day precipitation, and mean sea level rise — alongside information related to population density, agriculture, and built-up areas.

1.2.2 Environmental change

Most climate change impacts are exacerbated by environmental changes, such as land and sea use change (including agricultural intensification, increasing urbanisation and mass tourism, overfishing, land degradation and desertification), pollution (air, land, rivers, and ocean) and non-indigenous species (Cherif et al. 2020).

Sea, inland and air pollution in the Mediterranean is increasing both in quantity and in the number of pollutants. Pollution comes from transport, shipping, unsustainable agricultural, industry and household waste. The Mediterranean Basin is among the regions in the world with the highest concentrations of gaseous air pollutants (nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and ozone (O_3)). Fossil fuel use, industry, ships, and road traffic are the major emitters of SO_2 and nitrogen oxides (NO_x). Emissions of aerosols and particulate matter (PM) into the atmosphere come from anthropogenic activities (transport, industry, biomass burning, etc.), but also from natural sources (volcanic eruptions, sea salt, soil dust suspension, natural forest fires, etc.). Air pollution levels are enhanced by specific atmospheric circulation patterns and by dry and sunny climate (Schembari et al. 2012; Karanasiou et al. 2014; Dayan et al. 2017). Particular meteorological conditions and the proximity of the Sahara Desert influence particulate matter (PM) concentrations, including the occurrence of critically high PM concentrations associated with dust outbreaks, particularly in the southern Mediterranean (Ganor et al. 2010).

---

[18] IPCC likelihood language is introduced in *Section 1.4.2*.

[19] IPCC AR6 Synthesis Report (IPCC 2023): for 1850–1900 to 2013–2022 the updated calculations are 1.15 [1.00 to 1.25]°C for global surface temperature, 1.65 [1.36 to 1.90]°C for land temperatures, and 0.93 [0.73 to 1.04]°C for ocean temperatures above 1850–1900 using the exact same datasets (updated by 2 years) and methods as employed in IPCC (2021). Square brackets [x to y] are used to provide the assessed *very likely* range, or 90% interval.

Table 1.1 | Future global surface temperature change for the Mediterranean region. Change in global surface temperature relative to the period 1850–1900. Based on Coupled Model Intercomparison Project Phase 6 (CMIP6) model projections (34 models). Sourced from IPCC AR6 WGI Interactive Atlas (Gutiérrez et al. 2021).

Scenario (GHG emissions)	Near-term, 2021–2040		Medium-term, 2041–2060		Long-term, 2081–2100	
	Median (°C)	*Very likely* range (°C)	Median (°C)	*Very likely* range (°C)	Median (°C)	*Very likely* range (°C)
SSP1-2.6 (low)	1.8	1.4 to 2.2	2.1	1.6 to 2.7	2.2	1.6 to 3.0
SSP2.4.5 (medium)	1.9	1.5 to 2.3	2.4	1.9 to 3.1	3.3	2.4 to 4.3
SSP3-7.0 (high)	1.8	1.4 to 2.4	2.6	2.0 to 3.3	4.5	3.6 to 5.5
SSP5-8.5 (very high)	1.9	1.6 to 2.5	2.9	2.3 to 3.6	5.5	4.2 to 6.8

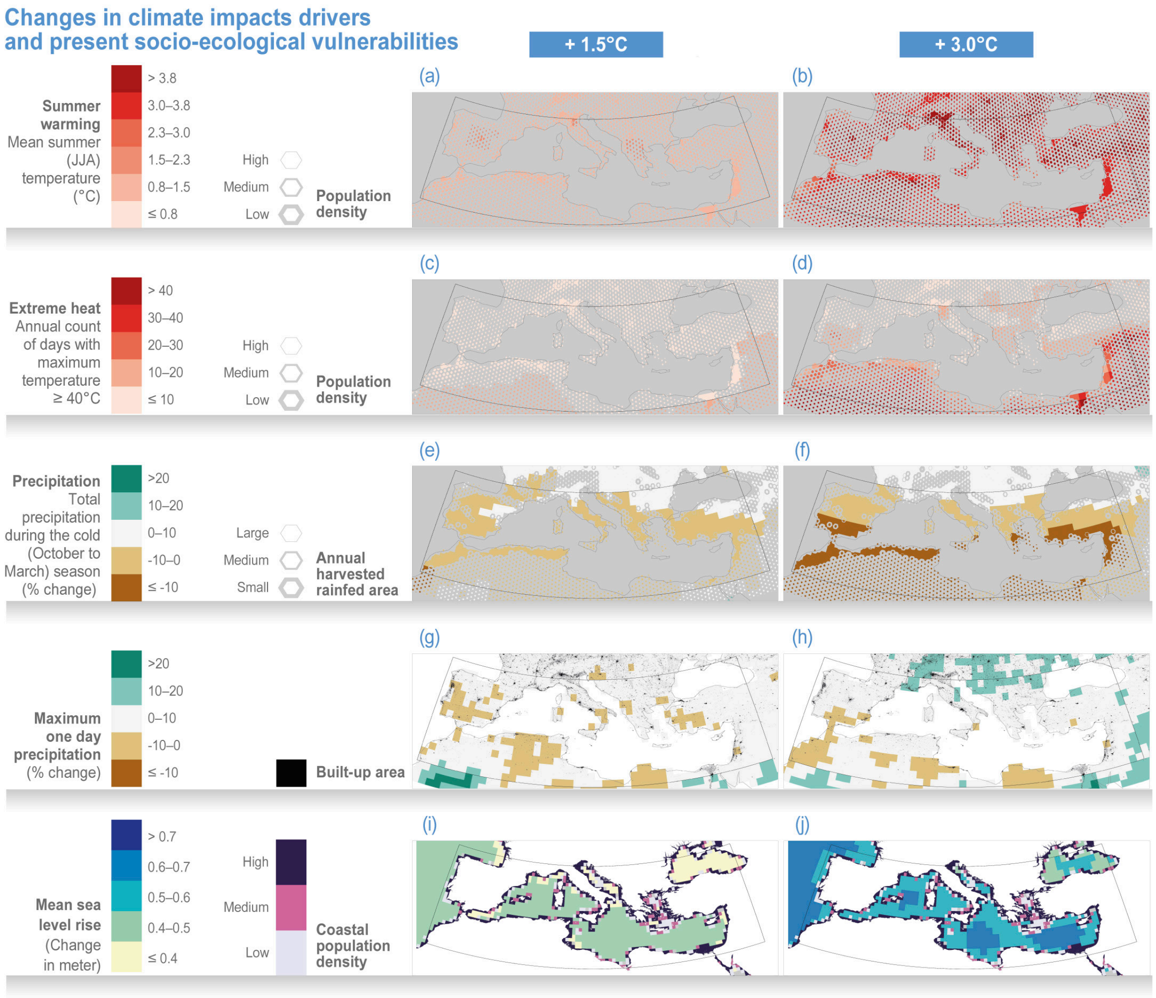


Figure 1.1 | Changes in climate impact drivers in the Mediterranean region. With respect to the 1995–2014 period for 1.5°C (left column) and 3°C (right column) global warming: mean summer (June to August) temperature (°C, a, b), number of days with maximum temperature above 40°C (days, c, d), total precipitation during the cold (October to March) season (%, e, f) and 1-day maximum precipitation (mm, g, h). Values are based on CMIP6 global projections and SSP5-8.5. Sea level rise concerns the long term (2081–2100) and SSP1-2.6 for (i) and SSP3-7.0 for (j). Source: Annex I: Atlas, IPCC (2022a). The figure is reproduced from Figure CCP4.2 in Ali et al. (2022).

Mediterranean coasts are polluted due to coastal squeeze (lack of accommodation space preventing landward transgression in response to e.g. sea level rise), intense industrialisation, uncontrolled discharges of municipal and industrial wastewater, riverine inputs and low seawater circulation. The Mediterranean Sea is heavily polluted by plastics, as 730 tonnes of plastic waste enter it daily. Plastic waste represents 95 to 100% of marine floating waste and 50% of litter on seabeds. There are many uncontrolled coastal landfill sites, particularly on the eastern and southern shores (reviewed in UNEP/MAP and Plan Bleu 2020). The increasing frequency of flash floods in the northern Mediterranean increases the supply of faecal bacteria, viruses and other contaminants to the coastal zone (Chu et al. 2011). In coastal zones, eutrophication caused by nutrient enrichment may provoke harmful and toxic algal blooms. These blooms may have negative economic impacts on fisheries, aquaculture, and tourism, as well as on human health, as 40% of blooming microalgae are able to produce toxins responsible for different human intoxications. Also, emerging contaminants (related recently to discovered chemicals or materials) may be harmful to people, causing disorders of the nervous, hormonal and reproductive system (Cherif et al. 2020).

Mediterranean coastal zones and their ecosystems are also impacted by non-indigenous species. Their number and spread are expected to increase in the future, and they may sometimes lead to a decrease or collapse in populations of native species (Corrales et al. 2018). Most marine non-indigenous species arrive from the Red Sea and Atlantic Ocean, but the highest impact is attributed to those introduced by ships and aquaculture (Katsanevakis et al. 2016). Among known marine non-indigenous species introduced over the last 30 years, invertebrates dominate with >58% (mostly mollusks and decapods), primary producers follow with approximately 23% and vertebrates with 18% (mostly fish) (Zenetos 2019).

Land use change, and particularly urbanisation, is a major driving force of biodiversity loss and biological homogenization causing landscape fragmentation (De Montis et al. 2017). Forest and shrub encroachment tend to increase in the northern Mediterranean, as a consequence of abandoned agro-pastoralism (Lasanta et al. 2017; Abadie et al. 2018), whereas in many regions of North Africa and the Middle East (but also on some Mediterranean islands), the dominant land use change processes are forest degradation and ecosystem fragmentation, caused by intensified agriculture, overgrazing and overexploitation of firewood (Hansen and DeFries 2004).

Marine resource overexploitation and unsustainable fishing practices provoke marine species population decline. Fishing efforts in the Mediterranean have increased over a long period, but particularly since the 1990's due to new technologies and higher capacity vessels (Colloca et al. 2017). In 2010, the cumulative percentage of collapsed and overexploited stocks exceeded 60% across the Mediterranean Sea, with the eastern Mediterranean being the most overexploited sub-basin (Tsikliras et al. 2013; Tsikliras et al. 2015).

Climate and environmental changes have become major threats to both ecosystems and human well-being in the Mediterranean and their impact is aggravated by ongoing socio-economic and demographic trends, including associated urbanisation and environmental losses. Disadvantaged or vulnerable populations, including the elderly, children, pregnant women, and people with low income, are particularly impacted.

1.2.3 Vulnerability, exposure, and impacts

The latest IPCC assessment (Ali et al. 2022; IPCC 2022c) on climate change impacts and vulnerability of Mediterranean countries confirm that all Mediterranean countries are vulnerable to several climate warming impacts. There are, however, local variations in exposure depending on the specific features and knowledge of each country, with southern and eastern countries presenting higher vulnerability. For example, North African countries are highly vulnerable to water stress and water scarcity in response to the growing demand for irrigation requirements for agriculture (e.g. Fader et al. 2016; World Bank 2018). Some countries (e.g. Egypt, Greece, and Spain) are suffering from salinisation of freshwater resources due to an increase in sea level rise and salt (Ali and El-Magd 2016; Wassef and Schüttrumpf 2016; Sebri 2017; UNDP 2018; Vargas and Paneque 2019).

Most socio-economic sectors in the Mediterranean region face increasing risks with agriculture followed by tourism being the most vulnerable (Kallis 2008; Kutiel 2019), together with high vulnerability along the North African coastal regions (UN ESCWA 2017).

Climate change will increase the vulnerability of MENA countries to food production at the local level as well as elsewhere (e.g. China and Russia) due to their high dependence on food imports (Waha et al. 2017). Exporting countries in the Mediterranean region (e.g. France, Italy, Morocco) also affect global food security by decreasing their availability, quality and quantity and increasing product prices. Fisheries in the Mediterranean Sea, which economically account for >3.4 billion USD (Randone et al. 2017), are also at greater risk of increased sea temperature with some locations more sensitive (Turan and Gürlek 2016; Ding et al. 2017; Hidalgo et al. 2018; Farahmand et al. 2023) and others less vulnerable (northern Mediterranean countries), with particular specifics for coastal cities (Keramaris et al. 2022; Schleyer-Lindenmann et al. 2022). Mediterranean forests, which are socially and ecologically important and contribute to several ecosystem services, are also vulnerable, particularly in countries in the northern and southwestern Mediterranean region (Ager et al. 2014; Gomes Da Costa et al. 2020). In addition to growing risks of coastal wildfires, climate change is causing increases in pest populations, such as the sharp increase in the Mediterranean bark beetle *(Orthotomicus erosus)* population size in Croatia (Lieutier and Paine 2016; Pernek et al. 2019).

The Mediterranean region is the leading tourism destination globally (Tovar-Sánchez et al. 2019). Both coastal and marine tourism industries in Mediterranean countries are vulnerable to climate change (Dogru et al. 2016; Dogru et al. 2019; Agulles et al. 2022). The economic value of this important sector, which generates annually from 100 billion USD (from marine activities) to 300 billion USD (from coastal activities), is expected to be significantly impacted (Radhouane 2013; Randone et al. 2017). Impacts on maritime transport and the trade industry in the region, with approximately 600 ports (all sizes and types), will also have consequences on their share in the GDP of about 20–40% of the regional GDP (Manoli 2021). Human health is also significantly vulnerable to climate change (Negev et al. 2015) and populations along the Mediterranean coastal areas are highly susceptible to several climate-related events, such as heat waves (Paz et al. 2016; Scortichini et al. 2018; Rohat et al. 2019) or tropical-like cyclones (Toomey et al. 2022), particularly for sensitive population groups (e.g. poor, ill, elderly, obese, children, and women) (Linares et al. 2015; Paravantis et al. 2017; Ali et al. 2022).

1.3 Coastal risks and adaptation in the Mediterranean Region

1.3.1 The risk framing of the report

Risk is usually estimated as the product of a hazard, times exposure and times the consequences of that hazard, estimated in terms of the impact produced by natural or human factors, using the conceptual framework of IPCC since AR5 (see Reisinger et al. 2020, for the consistent and transparent treatment of the concept of risk of the risk framework in the AR6). As a product of probabilities times damage, both referred to a selected spatial domain and for the time scale of the analysis, it is commonly expressed in a monetary unit (€, $, etc.). However, such an apparently simple concept presents multiple difficulties, some of them due to inconsistent language and others due to inherent uncertainties, particularly under future scenarios. These difficulties, aggravated by the limited size of extreme samples in the Mediterranean, have hindered a wider and harmonised uptake of risk applications for decision– and policy– making in this area. The risk analyses in this report combine data from different sources and publications, with different levels of review and cross-checking and should be applied with due caution for decisions that need to extrapolate the original results to wider domains or different time scales.

One of the main requirements to enable a comparison of risks for different coastal systems, typical of the high geodiversity and high meteo-oceanographic variability found in Mediterranean coasts, is the explicit definition of the spatial domain and time scale for which risks will be assessed, since the results will vary accordingly and will reflect different risk initiation and propagation mechanisms. The selection of temporal and spatial domains, together with the risk dimensions considered, will bound the multi-risk assessments nowadays required in many coastal assessments. The dimensions should consider which are the more relevant drivers (e.g. only sea level, sea level plus waves, etc.), responses (e.g. only erosion, erosion plus flooding, etc.) and interactions (e.g. marine, riverine, and pluvial flooding combined, response with or without rigid infrastructure, response with or without ecosystem services, etc.) for Mediterranean coasts. The selection of risk scales and dimensions should consider the aims of each application and the level of information available, particularly regarding plausible future climate and management scenarios for Mediterranean land and sea areas.

Regarding the spatial domain, coastal risks can be referred to the whole coastal zone for an integrated assessment or to a more constrained sector or component that is well-defined and whose interactions with the rest of the coastal system are well established. The difficulties in defining the land limit of the coastal zone illustrate the need for clear criteria, since it will critically influence any risk estimation. For instance, risk will be very different if the coastal zone limit is the first line of infrastructure, the landward limit of coastal cities, or the whole catchment basin that feeds that coast. This is particularly relevant for narrow emerged and submerged coastal zones so frequent in the Mediterranean (e.g. Rizzo et al. 2022).

Regarding the time domain, coastal risks should be referred to the horizons or intervals for which the risk is estimated, again well-defined according to the aims of each specific project. In common practice, risk estimates for coastal operational conditions should define which mean sea level and wave storm (energetic but not exceptional) associated with the time horizons. Risk estimates for survival conditions of a critical coastal infrastructure or system should define which extreme storms and range of high-end sea level increases must be considered. The same applies to risk assessments under frequent accidents (associated with the high density of population and activities in Mediterranean coastal zones) or under exceptional events (illustrated by medicanes or flash floods in the Mediterranean), which normally result in cascading risks that must also be considered in the analysis, leading to markedly different risk levels. Given the long-term commitment to sustainability and building resilience, uncertainty in the timing of reaching different levels of mean sea level rise is an important consideration for adaptation planning.

The same applies to risk assessments under frequent accidents. In addition to the domain and scales for risk estimation, practical applications and scientific analyses will benefit from an explicit list of the key risk variables, if possible, ranking them for the assessed risks. We suggest listing the main controlling variables characteristic of risk initiation and development for Mediterranean coastal zones, as presented for the various risk assessments in the following chapters. This listing should define key variables in unambiguous terms for specialists and stakeholders alike and distinguish between: (1) biophysical variables (such as sea level rise rate, peak significant wave height and for which return period, maximum storm surge level, safe pollutant concentrations for bathing, acceptable peak water temperatures and nutrient concentrations for aquaculture, etc.), and (2) socio-economic variables (population density and total population, typical average income, infrastructure density and built-up density, distance to an average shoreline, etc.).

1.3.2 Adaptation pathways

The risk reduction measures, and adaptation pathways presented in this report need temporal and spatial planning to enhance synergies (e.g. compatibility between short- and long-term interventions) and avoid undesired trade-offs, unacceptable risk levels (e.g. losing unique habitats or irreversible biodiversity degradation), or maladaptation. Here, adaptation pathways, understood as a sequenced combination of risk reduction interventions, offer an efficient approach, much required for the sustainability of Mediterranean coastal zones, to define possible alternatives (pathways), establish deadlines for these actions (tipping points) and suggest times to consider switching from one pathway to another (changing stations). Delineating such adaptation pathways may favour the inclusion of nature-based solutions in coastal protection plans (Sánchez-Arcilla et al. 2022), contributing to filling the implementation gap for the benefit of Mediterranean coastal areas. Such an approach should facilitate the convergence of stakeholders and scientists into more systemic analyses and interventions for coastal sustainability under climate change.

1.4 A guide to the assessment

1.4.1 Common dimensions of integration

The MedECC assessments, as with other international and national assessment processes, are based on the available, relevant evidence in the published literature. This includes different lines of evidence such as observational products, model-based findings and other information based on different types of data and analyses. To aid the communication of the report findings, in particular for the preparation of figures and to formulate executive summary statements of the assessment, a common set of key dimensions are used across the chapters to the extent possible. These dimensions are defined timeframes, common baselines for past changes and conditions, a subset of representative scenarios of future changes, and the use of well-known frameworks, such as the SDGs.

1.4.1.1 Timeframes

Three common time frames have been adopted by the IPCC Sixth Assessment Report to report key findings in time frames that are relevant for policymakers: near term — the period from 2020–2040 in the context of the timelines for current national emissions reduction pledges as part of the implementation of the Paris Agreement, and the implementation of the SDGs; the medium term — the period by 2041–2060, the mid-century timeframe relevant in the context of infrastructure planning; and the long term — the possible outcomes by 2080–2100 and beyond the end of the 21st century.

1.4.1.2 Baseline period

Changes in climate and in social and natural systems are compared to conditions that existed prior to the advent of rapid industrialisation in terms of fossil-fuel consumption and land-use changes. The period 1850–1900 has been assessed to be suitable as a proxy for pre-industrial conditions, a baseline against which observed historical changes in the climate system can be compared (see Cross-Chapter *Box 1.2* in IPCC 2021).

1.4.1.3 Future scenarios

Possible future scenarios form the basis of modelling and analytical studies to explore how socio-economic conditions, emissions of greenhouse gases, land use, the response of the climate system as well as natural and human systems may change in the 21st century and beyond. The international scientific community has developed different scenario frameworks over time with the aim to produce coordinated simulations across the community where datasets and findings can be compared. The latest generation of scenarios — the Shared Socio-Economic Pathways (SSPs) framework (O'Neill et al. 2017; Riahi et al. 2017) — is used to explore the climate response to human-caused drivers of climate change as part of the Coupled Model Intercomparison Project Phase 6 (CMIP6) of the World Climate Research Programme (WCRP).

The experimental design is built around a matrix of simulations that consider different socioeconomic developments and different levels of radiative forcing in the year 2100 levels (see Cross-Chapter *Box 1.4* in Chen et al. 2021). The assessment of future climate change, impacts, vulnerability, and adaptation actions can be compared for scenarios with high emissions (SSP3-7.0), based on futures with 'no-additional-climate-policy' (in the set of Representative Concentration Pathways (RCPs), the equivalent no additional-climate-policy' scenario was RCP8.5). The new SSP3-7.0 'no-additional-climate-policy' scenario, with intermediate greenhouse gas emissions (SSP2-4.5), and scenarios with very low and low greenhouse gas emissions (SSP1-1.9 and SSP1-2.6). Scenarios with very high greenhouse gas emissions (SSP5-8.5) have been assessed as being less *likely* in terms of future outcomes, so are not considered to be 'business-as-usual' scenarios any longer, based on today's climate policies (IPCC 2022c), though these scenarios cannot be ruled out altogether and are useful to explore low-likelihood, high-risk outcomes.

1.4.1.4 Sustainable Development Goals

The UN 2030 Agenda for Sustainable Development and its Sustainable Development Goals (SDGs) was established to focus international efforts on the multiple intersectionality between different development objectives, including for climate change, for the pursuit of the seventeen SDGs by 2030 (UN DESA 2015; UN General Assembly 2015). The Mediterranean Strategy for Sustainable Development (MSSD) 2016-2025 (UNEP/MAP 2016) provides an integrative policy framework for all stakeholders, including MAP partners, to translate the 2030 Agenda for Sustainable Development and the SDGs at the regional, sub-regional, national and local levels in the Mediterranean region. The SDGs are used in this report to relate the assessment to different development goals.

1.4.2 Communicating assessment findings consistently.

Within the intergovernmental context of the IPCC and MedECC, the assessment of the latest available climate science, environmental and socio-economic knowledge is solicited by policymakers through a science-policy interface to support the development of evidence-based policy development and communications activities in different sectors and contexts. The use of agreed terms that are calibrated to quantify the strength and quality of the available information distinguishes an assessment from a review of the available scientific and technical literature.

The framework of calibrated terms that communicate the robustness and certainty of assessment findings either qualitatively or quantitatively have been used across the IPCC since the 5th Assessment Report (AR5). This terminology was agreed on as an outcome of a Cross-Working Group Meeting on Consistent Treatment of Uncertainties convened in July 2010 for the consistent treatment of uncertainties in the assessment across all IPCC assessment reports (Mastrandrea and Mach 2011; Mastrandrea et al. 2011). It builds on previous applications in earlier reports (Moss and Schneider 2000; IPCC 2005). Mach et al. (2017) reported on the lessons learned from the AR5 and provided further guidance on the systematic use of the calibrated terms, considering challenges in communicating findings where there are considerable uncertainties or considering subjectivity in expert judgement. The transparent use of calibrated terms to build a shared understanding of the assessment outcomes is all the more important when evidence-based policymaking is set in the context of multiple influences including different value systems (see discussion in Chen et al. 2021).

The terms are calibrated to have the same meaning for a consistent presentation of the assessment across different chapters of a report, or topics assessed in a report or across different reports, in order to a consistent and comparable picture on the state of knowledge to policymakers. The terms are italicised in the text to clearly identify when they are used and that the meaning is intended to be distinct from an everyday use of these words. This is a powerful communication tool that is able to clearly transmit the key assessment findings to policymakers or other users more broadly, overcoming the complexity of the underlying literature, which may be based on different disciplines or methodologies, and in an assessment carried out by a diverse set of experts that will also come from different disciplines, contexts and countries.

The calibrated terms quantify:

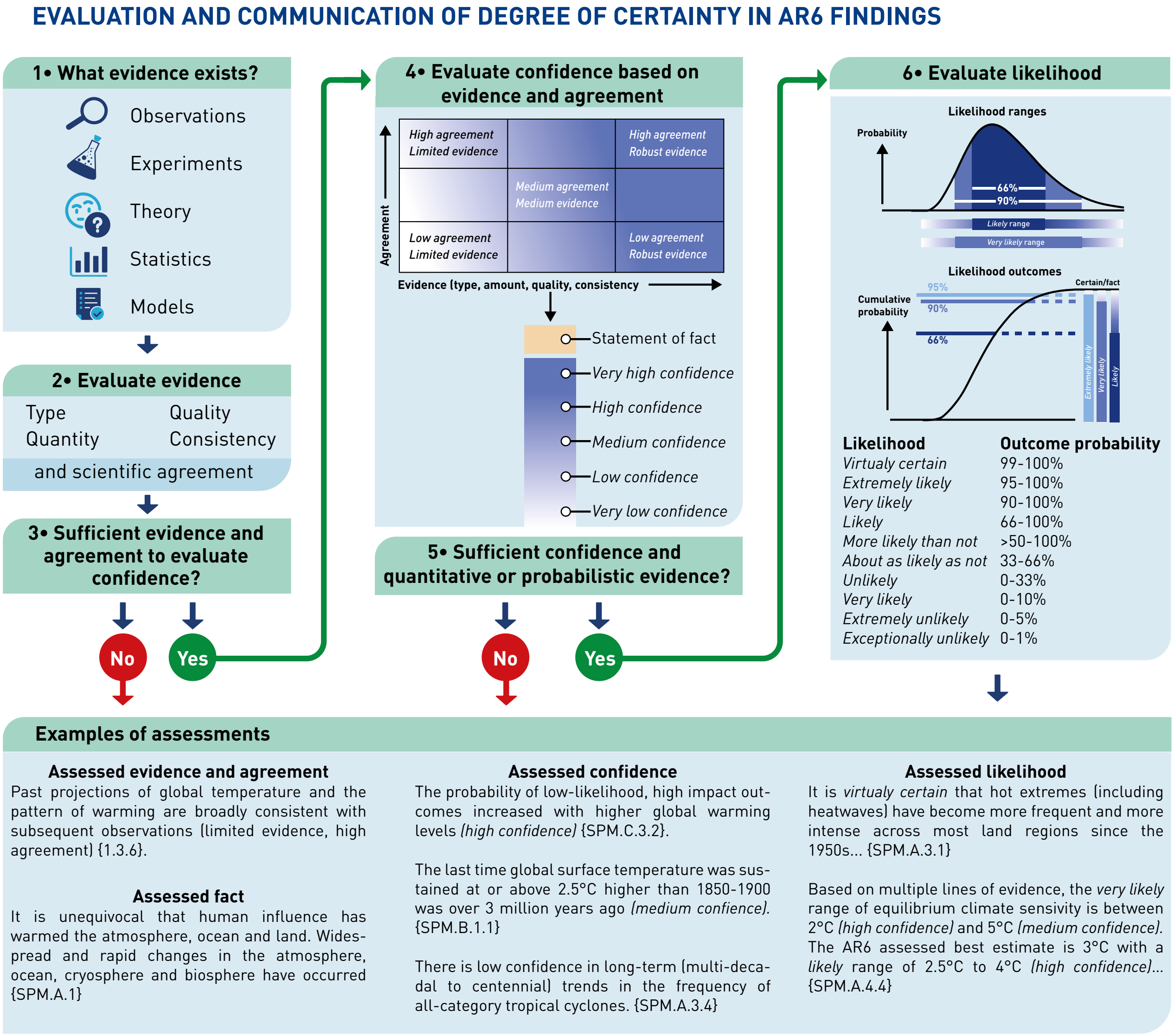
- **Confidence:** a qualitative measure of the robustness of a finding, based on the type, amount, quality and consistency of evidence and the degree of agreement across different lines of evidence or studies. Levels of confidence can be *very low, low, medium, high* and *very high.*

- **Likelihood:** a quantitative measure of uncertainty in a finding, expressed probabilistically, for example the *likely* outcome of a process[20]. This can be quantified based on statistical analyses, expert judgement by the author team or a formal quantitative survey of expert views (expert elicitation).

Figure 1.2 (Box 1.1 Figure 1 in Chen et al. 2021 adapted from Mach et al. 2017) illustrates the step-by-step process authors use to evaluate and communicate the state of knowledge in their assessment (Mastrandrea et al. 2010). The authors start by considering the relevant evidence in the published literature. They evaluate the different types of evidence, and the agreement in the findings therein

---

[20] The following terms have been used to indicate the assessed likelihood of an outcome or result: virtually certain 99–100% probability; very likely 90–100%; likely 66–100%; about as likely as not 33–66%; unlikely 0–33%; very unlikely 0–10%; and exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%; more likely than not >50–100%; and extremely unlikely 0–5%) are also used when appropriate. Assessed likelihood is typeset in italics, for example, *very likely.*



Likelihood	Outcome probability
Virtualy certain	99-100%
Extremely likely	95-100%
Very likely	90-100%
Likely	66-100%
More likely than not	>50-100%
About as likely as not	33-66%
Unlikely	0-33%
Very likely	0-10%
Extremely unlikely	0-5%
Exceptionally unlikely	0-1%

Assessed evidence and agreement

Past projections of global temperature and the pattern of warming are broadly consistent with subsequent observations (limited evidence, high agreement) {1.3.6}.

Assessed fact

It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred {SPM.A.1}

Assessed confidence

The probability of low-likelihood, high impact outcomes increased with higher global warming levels *(high confidence)* {SPM.C.3.2}.

The last time global surface temperature was sustained at or above 2.5°C higher than 1850-1900 was over 3 million years ago *(medium confience).* {SPM.B.1.1}

There is low confidence in long-term (multi-decadal to centennial) trends in the frequency of all-category tropical cyclones. {SPM.A.3.4}

Assessed likelihood

It is *virtualy certain* that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s... {SPM.A.3.1}

Based on multiple lines of evidence, the *very likely* range of equilibrium climate sensitivity is between 2°C *(high confidence)* and 5°C *(medium confidence)*. The AR6 assessed best estimate is 3°C with a *likely* range of 2.5°C to 4°C *(high confidence)*... {SPM.A.4.4}

Figure 1.2 | Characterising understanding and uncertainty in assessment findings. Adapted from Box 1.1, Figure 1 in IPCC (2021).

(Steps 1 and 2). From this, authors decide whether they can assign a level of confidence (Steps 3 and 4), likelihood (Step 5) of the assessed information to communicate their expert judgement of the robustness of the findings. Example statements of assessment conclusions drawn from the report are presented in the box at the bottom of *Figure 1.2.*

Each chapter subsection on a topic presents a traceable account of the assessment, starting with an introduction of the topic, what previous assessments had concluded, then discusses the relevant body of literature, including what methods have been used, the understanding of processes and mechanisms and the relevance of these findings, then concluding in an assessment statement that summarises the state of knowledge on this topic. The terms are attributed to the assessment outcome by the author team following an evaluation of the available evidence. They are agreed on through a consensus-building discussion of the evidence, reflecting all expert views that are expressed.

1.4.3 Values and the interplay with nature and society

Risk of sea level rise along the coastline impacts physical locations and social activities. To inform adaptation policy, it is necessary to understand how risks are distributed within and among communities.

Responding to this need, a value-based approach guides the understanding between nature and society, placing social and cultural values in the geographic space. The approach explores what people value most about their everyday lives, and how these social values are *likely* to be affected by environmental changes and the policies developed to respond to such changes (Persson et al. 2015).

In the context of parts of the Mediterranean coastlines that are densely populated and built up, it is essential to follow a value-based approach to examine the interplay between nature and the potential social impacts of sea level rise. Some essential social values highly important to residents include scenery, livelihoods, and safety. However, local communities have unique social values. Recent studies are facilitating the interplay of social values and natural risks. There is great potential to further integrate natural and social approaches to better inform adaptation policy about how lived and landscape values are distributed among communities (Ramm et al. 2017).

1.4.4 Ethical considerations

Some adaptation plans for Mediterranean coasts have been designed by local and regional administrations typically focusing on the need to protect local communities, and to minimise short-term impacts on the natural environment, such as ensuring local ecosystem resilience. A notable absence from many plans, in the Mediterranean and elsewhere, is the ethical approach needed to present the inherent uncertainties in any assessment, particularly for climates like the Mediterranean, where extreme samples are more limited in size than for other coastal areas. Such an ethical dimension is particularly relevant for Mediterranean assessments, which affect coastal areas with a high level of vulnerabilities due to conflicting uses and limitations of natural resources. This ethical approach should lead to better informed and more widely accepted adaptation policies.

However, there are knowledge gaps on the risks and vulnerabilities of many non-material social and environmental values. While values-based approaches are receiving increased attention by scholars, it is unclear to what extent they are being adopted by decision-makers (Ramm et al. 2017) and this applies to all coastal zones. However, the urgency for filling that gap is more acute in the Mediterranean due to the combination of climate and human pressures.

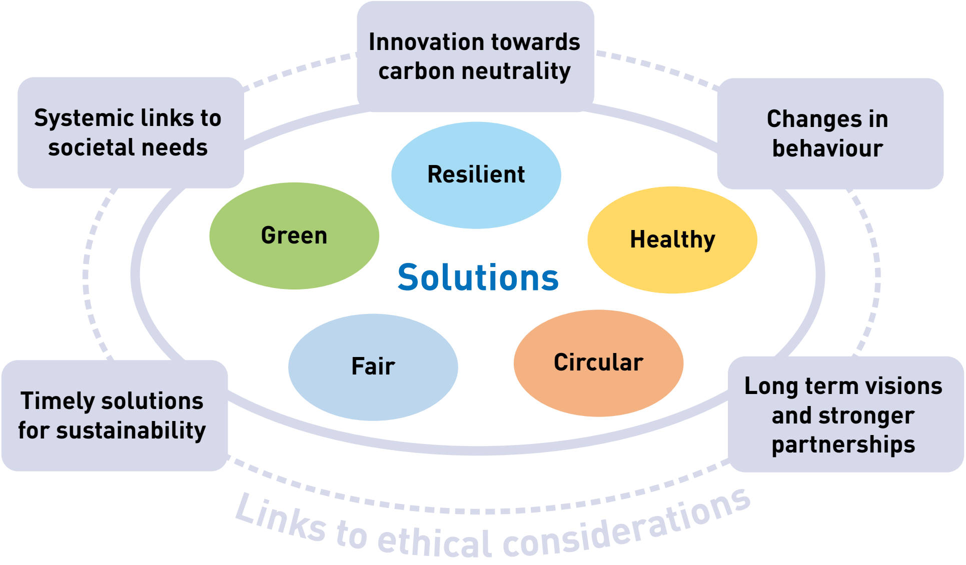


Figure 1.3 | A framework for coastal risk management that includes the systemic evaluation of the solutions and the ethical considerations of the assessment process. In the inner circle the attributes of the solutions: resilient, healthy, circular, fair, and green. In the outer circle, the ethical considerations: systemic links to societal needs, innovation towards carbon neutrality, changes in behaviour, long term visions and stronger partnerships and timely solutions towards sustainability.

Graham et al. (2014) proposed that values-based approaches could direct policymakers towards ethical considerations in the adaptation process, giving voice to the impacted communities and their social and cultural landscape values. Because of these reasons, the ethical approach should be inclusive and collaborative, enabling decisions that consider diverse values and priorities (Ramm et al. 2017).

The ethical considerations within coastal assessments under climate change and management scenarios can only be addressed in a systemic approach that includes fairness, resiliency, health, circularity, and carbon neutrality. These values establish clear connections to systemic links for the main elements to be considered in an ethically-based assessment: societal needs, innovation, behavioural change, and long-term visions of society, including the active participation of women and marginalised and/or vulnerable groups. Clearly, the process is complex, as summarised schematically in *Figure 1.3,* and demands additional multidisciplinary data to better characterise Mediterranean coastal zones under the impact of future climate scenarios.

References

Abadie J., Dupouey J. L., Avon C., Rochel X., Tatoni T., and Bergès L. (2018). Forest recovery since 1860 in a Mediterranean region: drivers and implications for land use and land cover spatial distribution. *Landscape Ecology,* 33(2), 289–305. doi: 10.1007/s10980-017-0601-0

Ager A. A., Preisler H. K., Arca B., Spano D., and Salis M. (2014). Wildfire risk estimation in the Mediterranean area. *Environmetrics*, 25(6), 384–396. doi: 10.1002/env.2269

Agulles M., Melo-Aguilar C., and Jordà G. (2022). Risk of loss of tourism attractiveness in the Western Mediterranean under climate change. *Frontiers in Climate, 4*. doi: 10.3389/fclim.2022.1019892

Ali E., Cramer W., Carnicer J., Georgopoulou E., Hilmi N. J. M., Le Cozannet G., and Lionello P. (2022). Cross-Chapter Paper 4: Mediterranean Region. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2233–2272. doi: 10.1017/9781009325844.021

Ali E. M., and El-Magd I. A. (2016). Impact of human interventions and coastal processes along the Nile Delta coast, Egypt during the past twenty-five years. *The Egyptian Journal of Aquatic Research,* 42(1), 1–10. doi: 10.1016/j.ejar.2016.01.002

Chen D., Rojas M., Samset B. H., Cobb K., Diongue-Niang A., Edwards P., Emori S., Faria S. H., Hawkins E., Hope P., Huybrechts P., Meinshausen M., Mustafa S. K., Plattner G.-K., and Tréguier A. M. (2021). Framing, context, and methods. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, Ö. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 147–286. doi: 10.1017/9781009157896.003

Cherif S., Doblas-Miranda E., Lionello P., Borrego C., Giorgi F., Iglesias A., Jebari S., Mahmoudi E., Moriondo M., Pringault O., Rilov G., Somot S., Tsikliras A., Vila M., and Zittis G. (2020). Drivers of change. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental Change in the Mediterranean Basin–Current Situation and Risks for the Future. First Mediterranean Assessment Report.* Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, pp. 59-180. doi: 10.5281/zenodo.7100601

Chu Y., Salles C., Tournoud M. G., Got P., Troussellier M., Rodier C., and Caro A. (2011). Faecal bacterial loads during flood events in Northwestern Mediterranean coastal rivers. *Journal of Hydrology,* 405(3–4), 501–511. doi: 10.1016/j.jhydrol.2011.05.047

Colloca F., Scarcella G., and Libralato S. (2017). Recent Trends and Impacts of Fisheries Exploitation on Mediterranean Stocks and Ecosystems. *Frontiers in Marine Science, 4,* 244. doi: 10.3389/fmars.2017.00244

Corrales X., Coll M., Ofir E., Heymans J. J., Steenbeek J., Goren M., Edelist D., and Gal G. (2018). Future scenarios of marine resources and ecosystem conditions in the Eastern Mediterranean under the impacts of fishing, alien species and sea warming. *Scientific Reports, 8*(1), 14284. doi: 10.1038/s41598-018-32666-x

Dayan U., Ricaud P., Zbinden R., and Dulac F. (2017). Atmospheric pollution over the eastern Mediterranean during summer - a review. *Atmospheric Chemistry and Physics, 17*(21), 13233–13263. doi: 10.5194/acp-17-13233-2017

De Montis A., Martín B., Ortega E., Ledda A., and Serra V. (2017). Landscape fragmentation in Mediterranean Europe: A comparative approach. *Land Use Policy,* 64, 83–94. doi: 10.1016/j.landusepol.2017.02.028

Ding Q., Chen X., Hilborn R., and Chen Y. (2017). Vulnerability to impacts of climate change on marine fisheries and food security. *Marine Policy, 83,* 55–61. doi: 10.1016/j.marpol.2017.05.011

Dogru T., Bulut U., and Sirakaya-Turk E. (2016). Theory of Vulnerability and Remarkable Resilience of Tourism Demand to Climate Change: Evidence from the Mediterranean Basin. *Tourism Analysis, 21*(6), 645–660. doi: 10.3727/108354216x14713487283246

Dogru T., Marchio E. A., Bulut U., and Suess C. (2019). Climate change: Vulnerability and resilience of tourism and the entire economy. *Tourism Management, 72,* 292–305. doi: 10.1016/j.tourman.2018.12.010

EC Secretariat-General (2019). *European Green Deal. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions — The European Green Deal (COM(2019) 640 final, 11.12.2019).* doi: 10.2775/373022

Fader M., Shi S., Von Bloh W., Bondeau A., and Cramer W. (2016). Mediterranean irrigation under climate change: more efficient irrigation needed to compensate for increases in irrigation water requirements. *Hydrology and Earth System Sciences, 20*(2), 953–973. doi: 10.5194/hess-20-953-2016

Farahmand S., Hilmi N., Cinar M., Safa A., Lam V. W. Y., Djoundourian S., Shahin W., Ben Lamine E., Schickele A., Guidetti P., Allemand D., and Raybaud V. (2023). Climate change impacts on Mediterranean fisheries: A sensitivity and vulnerability analysis for main commercial species. *Ecological Economics, 211,* 107889. doi: 10.1016/j.ecolecon.2023.107889

Ganor E., Osetinsky I., Stupp A., and Alpert P. (2010). Increasing trend of African dust, over 49 years, in the eastern Mediterranean. *Journal of Geophysical Research: Atmospheres, 115*(D7), 7201. doi: 10.1029/2009jd012500

Gomes Da Costa H., De Rigo D., Liberta` G., Durrant T., and San-Miguel-Ayanz J. (2020). *European wildfire danger and vulnerability in a changing climate: towards integrating risk dimensions: JRC PESETA IV project: Task 9 - forest fires.* Publications Office of the European Union, Luxembourg. doi: 10.2760/46951

Graham S., Barnett J., Fincher R., Hurlimann A., and Mortreux C. (2014). Local values for fairer adaptation to sea-level rise: A typology of residents and their lived values in Lakes Entrance, Australia. *Global Environmental Change, 29*, 41–52. doi: 10.1016/j.gloenvcha.2014.07.013

Gutiérrez J. M., Jones R. G., G.T. Narisma G. T., Alves L. M., Amjad M., Gorodetskaya I. V., Grose M., Klutse N. A. B., Krakovska S., Li J., Martínez-Castro D., Mearns L. O., Mernild S. H., Ngo-Duc T., van den Hurk B., and Yoon J.-H. (2021). Atlas. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1927–2058. doi: 10.1017/9781009157896.021

Hansen M. C., and DeFries R. S. (2004). Detecting Long-term Global Forest Change Using Continuous Fields of Tree-Cover Maps from 8-km Advanced Very High-Resolution Radiometer (AVHRR) Data for the Years 1982-99. *Ecosystems, 7*(7), 695–716. doi: 10.1007/s10021-004-0243-3

Hidalgo M., Mihneva V., Vasconcellos M., and Bernal M. (2018). Climate change impacts, vulnerabilities and adaptations: Mediterranean Sea and the Black Sea marine fisheries. In M. Barange, T. Bahri, M. C. M. Beveridge, K. L. Cochrane, S. Funge-Smith, & F. Poulain (Eds.), *Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options.* (pp. 139–157). FAO Fisheries and Aquaculture Technical Paper No. 627. Rome, FAO. https://openknowledge.fao.org/handle/20.500.14283/i9705en/

IPCC (2005). *Guidance notes for lead authors of the IPCC Fourth Assessment Report on addressing uncertainties.* Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-uncertaintyguidancenote-1.pdf

IPCC (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou, Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. doi: 10.1017/9781009157896

IPCC (2022a). Annex I: Global to Regional Atlas [Pörtner, H.-O., A. Alegría, V. Möller, E.S. Poloczanska, K. Mintenbeck, S. Götze (eds.)]. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2811-2896. doi: 10.1017/9781009325844.028

IPCC (2022b). Annex II: Glossary [Möller, V, J.B.R. Matthews, R. van Diemen, C. Méndez, S. Semenov, J.S. Fuglestvedt, A. Reisinger (eds.)]. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 2897–2930). Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2897-2930. doi: 10.1017/9781009325844.029

IPCC (2022c). Annex III: Scenarios and modelling methods [Guivarch, C., E. Kriegler, J. Portugal-Pereira, V. Bosetti, J. Edmonds, M. Fischedick, P. Havlík, P. Jaramillo, V. Krey, F. Lecocq, A. Lucena, M. Meinshausen, S. Mirasgedis, B. O'Neill, G.P. Peters, J. Rogelj, S. Rose, Y. Saheb, G. Strbac, A. Hammer Strømman, D.P. van Vuuren, N. Zhou (eds)]. In P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley (Eds.), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.022

IPCC (2022d). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama, Eds.). Cambridge University Press. Cambridge, UK and New York, NY, USA, 3056 pp. doi: 10.1017/9781009325844

IPCC (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Core Writing Team, H. Lee, & J. Romero, Eds.). IPCC, Geneva, Switzerland, pp. 35-115. doi: 10.59327/IPCC/AR6-9789291691647

Kallis G. (2008). Droughts. *Annual Review of Environment and Resources, 33,* 85–118. doi: 10.1146/annurev.environ.33.081307.123117

Karanasiou A., Querol X., Alastuey A., Perez N., Pey J., Perrino C., Berti G., Gandini M., Poluzzi V., Ferrari S., de la Rosa J., Pascal M., Samoli E., Kelessis A., Sunyer J., Alessandrini E., Stafoggia M., and Forastiere F. (2014). Particulate matter and gaseous pollutants in the Mediterranean Basin: Results from the MED-PARTICLES project. *Science of The Total Environment, 488–489,* 297–315. doi: 10.1016/j.scitotenv.2014.04.096

Katsanevakis S., Tempera F., and Teixeira H. (2016). Mapping the impact of alien species on marine ecosystems: the Mediterranean Sea case study. *Diversity and Distributions, 22*(6), 694–707. doi: 10.1111/ddi.12429

Keramaris E., De Paola F., Guida C., Gargiulo C., Papa R., and Carpentieri G. (2022). Vulnerability and Exposure of Mediterranean Coastal Cities to Climate Change-Related Phenomena. *Environmental Sciences Proceedings 2022, Vol. 21, Page 79, 21*(1), 79. doi: 10.3390/environsciproc2022021079

Kutiel H. (2019). Climatic Uncertainty in the Mediterranean Basin and Its Possible Relevance to Important Economic Sectors. *Atmosphere, 10*(1), 10. doi: 10.3390/atmos10010010

Lasanta T., Arnáez J., Pascual N., Ruiz-Flaño P., Errea M. P., and Lana-Renault N. (2017). Space–time process and drivers of land abandonment in Europe. *CATENA, 149,* 810–823. doi: 10.1016/j.catena.2016.02.024

Lieutier F., and Paine T. D. (2016). Responses of mediterranean forest phytophagous insects to climate change. In T. Paine & F. Lieutier (Eds.), *Insects and Diseases of Mediterranean Forest Systems* (pp. 801–858). Springer International Publishing. doi: 10.1007/978-3-319-24744-1_28

Linares C., Sánchez R., Mirón I. J., and Díaz J. (2015). Has there been a decrease in mortality due to heat waves in Spain? Findings from a multicity case study. *Journal of Integrative Environmental Sciences, 12*(2), 153–163. doi: 10.1080/1943815x.2015.1062032

Mach K. J., Mastrandrea M. D., Freeman P. T., and Field C. B. (2017). Unleashing expert judgment in assessment. *Global Environmental Change, 44,* 1–14. doi:10.1016/j.gloenvcha.2017.02.005

Manoli P. (2021). *Economic Linkages across the Mediterranean: Trends on trade, investments and energy.* Policy Paper # 52/2021, Hellenic Foundation for European & foreign policy (ELIAMEP), Greece, Athens. https://www.eliamep.gr/wp-content/uploads/2021/01/Policy-paper-52-Manoli-final.pdf

Mastrandrea M. D., Field C., Stocker T., Edenhofer O., Ebi K., Frame D., Held H., Kriegler E., Mach K., Matschoss P., Plattner G.-K., Yohe G., and Zwiers F. (2010). *Guidance note for lead authors of the IPCC Fifth Assessment Report on consistent treatment of uncertainties.* Intergovernmental Panel on Climate Change (IPCC), 7 pp. www.ipcc.ch/site/assets/uploads/2017/08/AR5_Uncertainty_Guidance_Note.pdf

Mastrandrea M. D., and Mach K. J. (2011). Treatment of uncertainties in IPCC Assessment Reports: Past approaches and considerations for the Fifth Assessment Report. *Climatic Change, 108*(4), 659–673. doi: 10.1007/s10584-011-0177-7

Mastrandrea M. D., Mach K. J., Plattner G.-K., Edenhofer O., Stocker T. F., Field C. B., Ebi K. L., and Matschoss P. R. (2011). The IPCC AR5 guidance note on consistent treatment of uncertainties: a common approach across the working groups. *Climatic Change, 108*(4), 675–691. doi: 10.1007/s10584-011-0178-6

MedECC (2020a). *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report* (W. Cramer, J. Guiot, & K. Marini, Eds.). Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, 632 pp. doi: 10.5281/zenodo.4768833

MedECC (2020b). Summary for Policymakers. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report.* Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, pp 11-40. doi: 10.5281/zenodo.5513887

Moss R. H., and Schneider S. H. (2000). Uncertainties in the IPCC TAR: Recommendations to lead authors for more consistent assessment and reporting. In R. Pachauri, T. Taniguchi, & K. Tanaka (Eds.), *Guidance Papers on the Cross Cutting Issues of the Third Assessment Report of the IPCC [Pachauri, R., T. Taniguchi, and K. Tanaka (eds.)].* World Meteorological Organization (WMO), Geneva, Switzerland, pp. 33–51. https://stephenschneider.stanford.edu/Publications/PDF_PapersUncertaintiesGuidanceFinal2.pdf

Negev M., Paz S., Clermont A., Pri-Or N. G., Shalom U., Yeger T., and Green M. S. (2015). Impacts of Climate Change on Vector Borne Diseases in the Mediterranean Basin - Implications for Preparedness and Adaptation Policy. *International Journal of Environmental Research and Public Health, 12*(6), 6745–6770. doi: 10.3390/ijerph120606745

O'Neill B. C., Kriegler E., Ebi K. L., Kemp-Benedict E., Riahi K., Rothman D. S., van Ruijven B. J., van Vuuren D. P., Birkmann J., Kok K., Levy M., and Solecki W. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change, 42,* 169–180. doi: 10.1016/j.gloenvcha.2015.01.004

Paravantis J., Santamouris M., Cartalis C., Efthymiou C., and Kontoulis N. (2017). Mortality Associated with High Ambient Temperatures, Heatwaves, and the Urban Heat Island in Athens, Greece. *Sustainability, 9*(4), 606. doi: 10.3390/su9040606

Paz S., Negev M., Clermont A., and Green M. S. (2016). Health Aspects of Climate Change in Cities with Mediterranean Climate, and Local Adaptation Plans. *International Journal of Environmental Research and Public Health, 13*(4), 438. doi: 10.3390/ijerph13040438

Pernek M., Lacković N., Lukić I., Zorić N., and Matošević D. (2019). Outbreak of Orthotomicus erosus (Coleoptera, Curculionidae) on Aleppo Pine in the Mediterranean Region in Croatia. South-East European Forestry, 10(1), 19–27. doi: 10.15177/seefor.19-05

Persson J., Sahlin N. E., and Wallin A. (2015). Climate change, values, and the cultural cognition thesis. *Environmental Science & Policy, 52,* 1–5. doi: 10.1016/j.envsci.2015.05.001

Radhouane L. (2013). Climate change impacts on North African countries and on some Tunisian economic sectors. *Journal of Agriculture and Environment for International Development (JAEID),* 107(1), 101–113. doi: 10.12895/jaeid.20131.123

Ramm T. D., Graham S., White C. J., and Watson C. S. (2017). Advancing values-based approaches to climate change adaptation: A case study from Australia. Environmental Science & Policy, 76, 113–123. doi: 10.1016/j.envsci.2017.06.014

Randone M., Di Carlo G., Costantini M., Tzanetti T., Haferkamp D., Portafaix A., Smits M., Antoniades V., Kachaner N., and Osborne A. (2017). Reviving the economy of the Mediterranean Sea: actions for a sustainable future. WWF Mediterranean Marine Initiative, Rome, Italy. https://wwfeu.awsassets.panda.org/downloads/reviving_mediterranean_sea_economy_full_rep_lowres.pdf

Reimann L., Vafeidis A. T., Brown S., Hinkel J., and Tol R. S. J. (2018). Mediterranean UNESCO World Heritage at risk from coastal flooding and erosion due to sea-level rise. *Nature Communications, 9,* 4161. doi: 10.1038/s41467-018-06645-9

Reisinger A., Howden M., Vera C., Garschagen M., Hurlbert M., Kreibiehl S., Mach K. J., Mintenbeck K., O'Neill B., Pathak M., Pedace R., Pörtner H.-O., Poloczanska E., Rojas Corradi M., Sillmann J., Van Aalst M., Viner D., Jones R., Ruane A. C., and Ranasinghe R. (2020). *The Concept of Risk in the IPCC Sixth Assessment Report: A Summary of Cross-Working Group Discussions.* Intergovernmental Panel on Climate Change, Geneva, Switzerland. https://www.ipcc.ch/site/assets/uploads/2021/02/Risk-guidance-FINAL_15Feb2021.pdf

Riahi K., van Vuuren D. P., Kriegler E., Edmonds J., O'Neill B. C., Fujimori S., Bauer N., Calvin K., Dellink R., Fricko O., Lutz W., Popp A., Cuaresma J. C., KC S., Leimbach M., Jiang L., Kram T., Rao S., Emmerling J., … Tavoni M. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change, 42,* 153–168. doi: 10.1016/j.gloenvcha.2016.05.009

Ribas A., Olcina J., and Sauri D. (2020). More exposed but also more vulnerable? Climate change, high intensity precipitation events and flooding in Mediterranean Spain. *Disaster Prevention and Management: An International Journal, 29*(3), 229–248. doi: 10.1108/dpm-05-2019-0149

Rizzo A., Vandelli V., Gauci C., Buhagiar G., Micallef A. S., and Soldati M. (2022). Potential Sea Level Rise Inundation in the Mediterranean: From Susceptibility Assessment to Risk Scenarios for Policy Action. *Water, 14*(3), 416. doi: 10.3390/w14030416

Rohat G., Flacke J., Dosio A., Pedde S., Dao H., and van Maarseveen M. (2019). Influence of changes in socioeconomic and climatic conditions on future heat-related health challenges in Europe. *Global and Planetary Change, 172,* 45–59. doi: 10.1016/j.gloplacha.2018.09.013

Samper Y., Liste M., Mestres M., Espino M., Sánchez-Arcilla A., Sospedra J., González-Marco D., Isabel Ruiz M., and Álvarez Fanjul E. (2022). Water Exchanges in Mediterranean Microtidal Harbours. *Water, 14*(13), 2012. doi: 10.3390/w14132012

Sánchez-Arcilla A., Cáceres I., Roux X. Le, Hinkel J., Schuerch M., Nicholls R. J., Otero D. M., Staneva J., De Vries M., Pernice U., Briere C., Caiola N., Gracia V., Ibáñez C., and Torresan S. (2022). Barriers and enablers for upscaling coastal restoration. Nature-Based Solutions, 2, 100032. doi: 10.1016/j.nbsj.2022.100032

Sánchez-Arcilla A., Lin-Ye J., García-León M., Gràcia V., and Pallarès E. (2019). The land–sea coastal border: a quantitative definition by considering the wind and wave conditions in a wave-dominated, micro-tidal environment. *Ocean Science, 15*(1), 113–126. doi: 10.5194/os-15-113-2019

Sarkar N., Rizzo A., Vandelli V., and Soldati M. (2022). A Literature Review of Climate-Related Coastal Risks in the Mediterranean, a Climate Change Hotspot. *Sustainability (Switzerland), 14*(23), 15994. doi: 10.3390/su142315994

Schembari C., Cavalli F., Cuccia E., Hjorth J., Calzolai G., Pérez N., Pey J., Prati P., and Raes F. (2012). Impact of a European directive on ship emissions on air quality in Mediterranean harbours. *Atmospheric Environment, 61*, 661–669. doi: 10.1016/j.atmosenv.2012.06.047

Schleyer-Lindenmann A., Mudaliar R., Rishi P., and Robert S. (2022). Climate change and adaptation to coastal risks as perceived in two major coastal cities: An exploratory study in Marseilles and Nice (France). *Ocean & Coastal Management, 225*, 106209. doi: 10.1016/j.ocecoaman.2022.106209

Scortichini M., De'Donato F., De Sario M., Leone M., Åström C., Ballester F., Basagaña X., Bobvos J., Gasparrini A., Katsouyanni K., Lanki T., Menne B., Pascal M., and Michelozzi P. (2018). The inter-annual variability of heat-related mortality in nine European cities (1990-2010). *Environmental Health: A Global Access Science Source, 17*(1), 66. doi: 10.1186/s12940-018-0411-0

Sebri M. (2017). Bridging the Maghreb's water gap: from rationalizing the virtual water trade to enhancing the renewable energy desalination. *Environment, Development and Sustainability, 19*(5), 1673–1684. doi: 10.1007/s10668-016-9820-9

Toomey T., Amores A., Marcos M., Orfila A., and Romero R. (2022). Coastal Hazards of Tropical-Like Cyclones Over the Mediterranean Sea. *Journal of Geophysical Research: Oceans, 127*(2). doi: 10.1029/2021jc017964

Tovar-Sánchez A., Sánchez-Quiles D., and Rodríguez-Romero A. (2019). Massive coastal tourism influx to the Mediterranean Sea: The environmental risk of sunscreens. *Science of The Total Environment, 656*, 316–321. doi: 10.1016/j.scitotenv.2018.11.399

Tsikliras A. C., Dinouli A., and Tsalkou E. (2013). Exploitation trends of the Mediterranean and Black Sea fisheries. *Acta Adriatica, 54*(2), 273–282. https://hrcak.srce.hr/117688

Tsikliras A. C., Dinouli A., Tsiros V. Z., and Tsalkou E. (2015). The Mediterranean and Black Sea Fisheries at Risk from Overexploitation. *PLoS ONE, 10*(3), e0121188. doi: 10.1371/journal.pone.0121188

Turan C., and Gürlek M. (2016). Climate Change and Biodiversity Effects in Turkish Seas. *Natural and Engineering Sciences, 1*(2), 15–24. doi: 10.28978/nesciences.286240

UfM (2021). *Declaration from 2nd Union for the Mediterranean Ministerial Conference on Environment and Climate Action.* https://ufmsecretariat.org//wp-content/uploads/2021/10/UfM-ministerial-declaration-ENV-CA_final-1-1.pdf

UN DESA (2015). *Global sustainable development report.* UN DESA, New York. https://digitallibrary.un.org/record/832718?v=pdf

UN ESCWA (2017). *Arab Climate Change Assessment Report – Main Report.* United Nations Economic and Social Commission for Western Asia, Beirut. E/ESCWA/SDPD/2017/RICCAR/Report. https://www.unescwa.org/publications/riccar-arab-climate-change-assessment-report

UNDP (2018). *Climate Change Adaptation in the Arab States: Best practices and lessons learned.* UNDP, Bangkok. https://www.undp.org/publications/climate-change-adaptation-arab-states

UNEP/MAP (2016). *Mediterranean Strategy for Sustainable Development 2016-2025.* Valbonne. Plan Bleu, Regional Activity Centre. https://wedocs.unep.org/bitstream/handle/20.500.11822/7097/mssd_2016_2025_eng.pdf

UNEP/MAP (2021a). Antalya Ministerial Declaration. In *Report of the 22nd Meeting of the Contracting Parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean and its Protocols. UNEP/MED IG.25/27* (pp. 103–108). UNEP/MAP, Athens. https://www.unep.org/unepmap/meetings/cop-decisions/cop22-outcome-documents

UNEP/MAP (2021b). Decision IG.25/4: Assessment Studies. In *Report of the 22nd Meeting of the Contracting Parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean and its Protocols.* UNEP/MED IG.25/27 (UNEP/MED IG.25/27; pp. 233–268). UNEP/MAP, Athens. https://www.unep.org/unepmap/meetings/cop-decisions/cop22-outcome-documents

UNEP/MAP, and Plan Bleu (2020). *State of the Environment and Development in the Mediterranean.* Nairobi. https://planbleu.org/wp-content/uploads/2021/04/SoED_full-report.pdf

Vargas J., and Paneque P. (2019). Challenges for the Integration of Water Resource and Drought-Risk Management in Spain. *Sustainability 2019,* 11(2), 308. doi: 10.3390/su11020308

Waha K., Krummenauer L., Adams S., Aich V., Baarsch F., Coumou D., Fader M., Hoff H., Jobbins G., Marcus R., Mengel M., Otto I. M., Perrette M., Rocha M., Robinson A., and Schleussner C. F. (2017). Climate change impacts in the Middle East and Northern Africa (MENA) region and their implications for vulnerable population groups. *Regional Environmental Change, 17*(6), 1623–1638. doi: 10.1007/s10113-017-1144-2

Wassef R., and Schüttrumpf H. (2016). Impact of sea-level rise on groundwater salinity at the development area western delta, Egypt. *Groundwater for Sustainable Development, 2–3,* 85–103. doi: 10.1016/j.gsd.2016.06.001

Wolff C., Nikoletopoulos T., Hinkel J., and Vafeidis A. T. (2020). Future urban development exacerbates coastal exposure in the Mediterranean. *Scientific Reports, 10*(1), 14420. doi: 10.1038/s41598-020-70928-9

World Bank (2018). *Beyond Scarcity: Water Security in the Middle East and North Africa.* MENA Development Report, World Bank, Washington, DC. http://hdl.handle.net/10986/27659

Zenetos A. (2019). Mediterranean Sea: 30 years of biogical invasions (1988-2017). In H. Langar & A. Ouerghi (Eds.), *Proceedings of the 1st Mediterranean Symposium on the Non-Indigenous Species (Antalya, Turkey, 18 January 2019)* (pp. 13–19). SPA/RAC, Tunis, 116 pp. https://www.racspa.org/sites/default/files/symposium/proceedings_msnis_2019_final.pdf

Information about the authors

Coordinating Lead Authors

Anna PIRANI, Euro-Mediterranean Centre on Climate Change (CMCC), *Venice, Italy*
Agustín SÁNCHEZ-ARCILLA, Laboratori d'Enginyeria Marítima, Universitat Politècnica de Catalunya · BarcelonaTech (UPC), *Barcelona, Spain*

Lead Authors

Elham ALI, Suez University / The National Authority for Remote Sensing & Space Sciences (NARSS), *Cairo, Egypt*
Ana IGLESIAS, Research Centre for the Management of Agricultural and Environmental Risks (CEIGRAM), Universidad Politécnica de Madrid (UPM), *Madrid, Spain*

Contributing Authors

Mounir GHRIBI, National Institute of Oceanography and Applied Geophysics (OGS), *Trieste, Italy*
Katarzyna MARINI, MedECC Secretariat / Plan Bleu, *Marseille, France*
Daria POVH ŠKUGOR, UN Environment Programme / Mediterranean Action Plan (UNEP/MAP), Priority Actions Programme Regional Activity Centre (PAP/RAC), *Split, Croatia*

Drivers and their interactions

2

Coordinating Lead Authors:
Murat BELIVERMIS *(Türkiye)*, **Dario CAMUFFO** *(Italy)*

Lead Authors:
Nuno CAIOLA *(Spain)*, **Claudio FERRARI** *(Italy)*, **Nadia MHAMMDI** *(Morocco)*,
Estela ROMERO *(Spain)*, **Claudia WOLFF** *(Germany)*

Contributing Authors:
Vincenzo ASERO *(Italy)*, **Sana BEN ISMAIL** *(Tunisia)*, **Cem DALYAN** *(Türkiye)*,
Hamouda DAKHLAOUI *(Tunisia)*, **Lena REIMANN** *(The Netherlands)*,
Alessio TEI *(Italy)*, **Matteo VACCHI** *(Italy)*, **Antonio della VALLE** *(Italy)*

This document should be cited as:
Belivermis, M., Camuffo, D., Caiola, N., Ferrari, C., Mhammdi, N., Romero, E., Wolff, C., 2024: Drivers and their Interactions. In: *Climate and Environmental Coastal Risks in the Mediterranean.* [Djoundourian, S., Lionello, P., Llasat, M.C., Guiot, J., Cramer, W., Driouech, F., Gattacceca, J.C., Marini, K. (eds.)]. MedECC Reports. MedECC Secretariat, Marseille, France, pp. 71-130, doi: 10.5281/zenodo.15096232

Chapter 2

Drivers and their interactions

Executive Summary

This chapter provides a comprehensive overview of the main natural and socio-economic drivers affecting the Mediterranean coasts. These drivers are of different origins and nature, including atmospheric, marine, terrestrial, biological, pollution-related, and socio-economic factors.

They contribute to phenomena such as coastal flooding, changes in ecosystem services, utilisation and exploitation of marine and coastal resources, degradation of natural and built infrastructure, among others, which impact the lives and livelihoods of the large and densely populated coastal areas and the proximate urban areas that depend heavily on marine and coastal resources. Some drivers are linked to climate change (exacerbated by human activities), while others are partially or entirely of anthropogenic origin (e.g. air and water pollution, tourism, urbanisation, socio-economic development). The situation can become complex as these drivers occur in temporal sequence, jointly, or in synergy. This chapter introduces the drivers, while their impacts are be considered in subsequent chapters.

Climate and geological drivers

Coastal air is warming. At the beginning of the 2020s, the near-surface air temperature of the Mediterranean region is +1.5°C warmer than in the 1850–1900 preindustrial period *(high confidence).* On the Mediterranean coasts, referring to the 1850–1900 period, there is *high confidence* that the projected increase in air temperature will be +1.6°C to +2.7°C for the medium term and +1.6°C to +3°C for the long term for the SSP1-2.6 low emission scenario *(very likely)* and values up to +2.3°C to +3.6°C for the medium term, and +4.2°C to +6.8°C for the long term, for the SSP5-8.5 very high emission scenario *(very likely)*. {2.2.1}

Coastal waters are warming. Since the preindustrial period, the surface temperature of the Mediterranean water has been rising with a long-term positive trend of about +0.86°C per century. This trend is not constant but is characterised by a multidecadal periodicity (~70 years) superimposed on it *(high confidence)*. {2.2.1}. Since the 1980s, satellite data has shown that the warming rate of the sea surface is spatially inhomogeneous, ranging between +0.29°C and +0.44°C per decade, and is stronger in the eastern Mediterranean. In addition, over the last two decades, the mean frequency of marine heat waves (MHW) has increased by +40%, and the duration by +15% *(high confidence)*. {2.2.5}

Significant warming is expected in the surface waters of the Mediterranean Sea *(virtually certain)*. Compared to the end of the 20th century, the annual mean basin sea surface temperature is expected to increase by +0.6°C to +1.3°C before the mid-21st century and by +2.7°C to +3.8°C at the end of the 21st century period for the pessimistic RCP8.5 scenario, and by +1.1°C to +2.1°C for the medium RCP4.5 scenario *(high confidence)*. {2.2.5}

Sea level is rising. Sea level changes have long been documented with instrumental and non-instrumental data. The pre-instrumental period is known from proxy data, tide gauges started in 1871, and satellite altimetry started in 1992. The rise rate increases over time, and the longest reconstructed series, for example Venice's seven century long record, shows an exponential trend *(observation evidence)*. {2.2.7}

The Mediterranean Sea level is projected to rise further during the coming decades and centuries *(high confidence)*, *likely* reaching +0.28 m to +0.55 m for shared socioeconomic pathways (SSP1-1.9) and +0.63 m to +1.01 m for SSP5-8.5 in 2100 (relative to 1995–2014) *(medium confidence)*. The process is irreversible at the scale of centuries to millennia *(high confidence)*. {2.2.7}

Land subsidence increases coastal submersion. Relative sea level is determined by the sum of the mean sea level and vertical land movements (i.e. negative subsidence and positive uplift). Relative sea level rise increases especially in areas affected by significant land subsidence. The situation across the European coasts has been documented by studies and especially satellite data (Copernicus Sentinel) since 2016, and the most affected areas are the coastal region of the Adriatic Sea and the Po Delta in Italy, Thessaloniki in Greece, and some small islands *(high confidence)*. The non-

European coasts on the eastern and southern Mediterranean are less documented, except for Mejerda near Tunis, and the eastern Nile Delta in Egypt *(high confidence).* Land subsidence is mainly determined by geological factors, but it may be increased by human activities, such as extraction of water, gases, or building load. In certain areas, subsidence may reach values of the order of –10 mm yr^{-1} *(observation evidence).* {2.2.8}

For the combined effect of sea level rise and subsidence, the risk of coastal floods will increase in low-lying areas that constitute 37% of the Mediterranean coastline *(high confidence)*. {2.2.4}

Saltwater intrusion in rivers, estuaries, and coastal aquifers will *likely* increase, affecting groundwater resources, river discharges, the use of coastal areas, and the most extensive wetlands that are found in relation to the major Mediterranean rivers *(high confidence)*. {2.2.4}

The main drivers of storm surges and coastal floods in the Mediterranean region vary by season. In the cold season, the penetration of Atlantic fronts, or low-pressure areas developing over the Mediterranean, may generate storm surges and exceptionally deep coastal floods, high wind waves and other phenomena such as flash floods that are potentially dangerous to people, the environment, and the whole coastal area *(high confidence).* {2.2.4}. In the warm season, increasing aridity or intense precipitation combined with occasional high intensity precipitation events will *likely* constitute the main challenges *(medium confidence).* {2.2.2}

Water salinity and acidity are related to water temperature. Not only temperature, but water salinity and acidity will also be affected, with *likely* impacts on the terrestrial and marine environment. Acidification is projected to continue *(virtually certain)* with a pH decrease of up to –0.46 unit in a high emission scenario *(medium confidence)*. {2.2.5}

Future reduced precipitation, associated with increased evaporation will lead to a decline in runoff in the Mediterranean region and fresh water supply. Droughts are projected to become more severe, more frequent and longer under moderate emission scenarios, and strongly enhanced under severe emission scenarios *(high confidence)* {2.2.6}

Biological drivers

With over a thousand non-indigenous species, the Mediterranean, which is a major invasion hotspot *(virtually certain)* is the most heavily invaded marine region in the world. Non-indigenous species outcompete indigenous species, causing regional biodiversity shifts and altering ecosystem functions and services *(high confidence).* The Suez Canal has provided the most important entrance for non-native species in the Mediterranean. At present, other pathways such as shipping vectors and the aquarium trade are responsible for a considerably higher number of the non-indigenous species that have been introduced. {2.3.1}

The Mediterranean is warming faster than other seas, becoming increasingly suitable to be colonised and invaded by organisms of tropical origin. The effect of global warming is therefore contributing to species colonisation through the Strait of Gibraltar, but also to the dispersal of these and truly non-indigenous species within the Mediterranean. Moreover, species are changing their life-history traits and patterns due to warming, which can lead to a loss of competitive abilities to cope with the effects of biological drivers, especially those caused by biological invasions. {2.3.2}

Recent studies show an increase in the frequency of jellyfish blooms in the Mediterranean Sea *(medium confidence).* There is some evidence that this is occurring due to eutrophication and other human-induced stressors, such as global warming *(medium confidence).* {2.3.3}

Pollution drivers

There is *robust evidence* that the high fluxes of nutrients transported by air, surface water, and groundwater to Mediterranean coasts are related to agricultural practices and urban and industrial uses. Nutrient fluxes are expected to decrease in the north due to the implementation of environmental regulations, but nutrient increases are expected in the south as a result of urban development and agricultural intensification *(high confidence).* Submarine groundwater discharge inputs, which lag a few decades behind agricultural inputs, can contribute to sustained nutrient increases in the coming years and compromise water quality *(medium confidence).* The overall projected changes in land-derived nutrients will contribute to widening the current nutrient imbalance in coastal ecosystems, increasing the availability of N relative to P and ultimately exacerbating eutrophication problems *(high agreement)*. {2.4.1}

Concentrations of certain persistent organic pollutants (POPs), such as polychlorinated biphenyl (PCBs) and dichlorodiphenyltrichloroethane (DDT), will *very likely* continue to decline in the Mediterranean coasts due to regulations *(medium confidence).* Concentrations of emerging pollutants, such as pharmaceuticals and personal care products, will not show a downward trend due to emerging industries and socioeconomic change *(medium confidence).* {2.4}

The amount of plastic pollution along Mediterranean coasts has remained steady for the past two decades *(medium confidence).* Annual plastic leakage into the Mediterranean coastal area is *likely* to reach 500,000 tonnes by 2040 if annual plastic production continues to grow at a rate of 4% and waste management is not radically improved. In the scenario of 1% annual growth in plastic production and improved waste management, the leakage is *likely* to decrease by 2040 *(medium confidence).* {2.4.4}

Given the high concentrations of plastics, trace elements and emerging pollutants in the Mediterranean Sea, their co-occurrence with seawater warming, acidification, and deoxygenation is *likely* to rise along the Mediterranean shores *(high confidence).* {2.2.5; 2.4}

Social and economic drivers

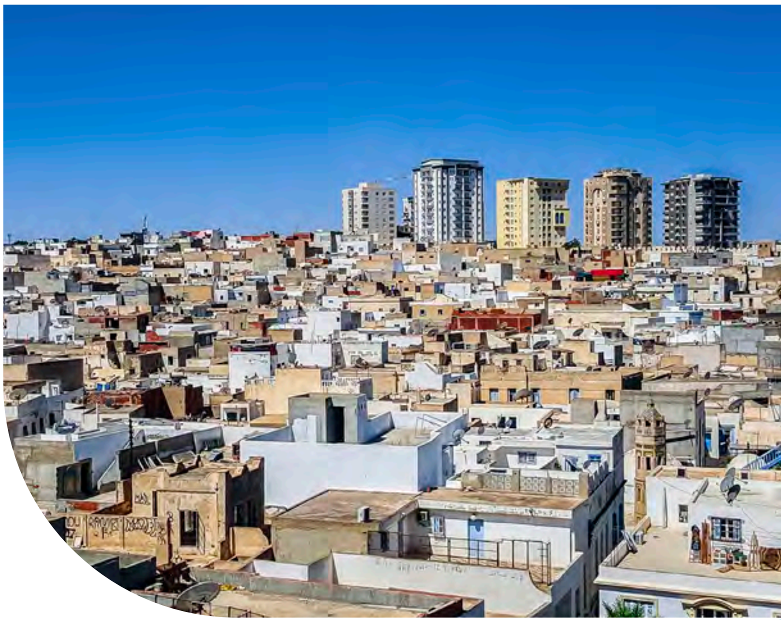
The Mediterranean countries have higher urbanisation rates than the rest of the world. Currently, two out of three people live in urban regions *(medium confidence).* In the past, socio-economic growth in the Mediterranean coastal region has been quite rapid and spatially diversified, leading to significant climate-related coastal exposure in all Mediterranean countries *(high confidence).* Under all socio-economic projections, the total population of the Mediterranean coastal region will continue to grow faster than the inland population *(medium confidence).* The coastal regions of the Mediterranean Middle East and Maghreb countries are anticipated to have the highest exposure to sea-level rise due to their projected coastal population growth. {2.5.1}

Climate change, with increasing sea level rise and storm frequency, will negatively impact port structures and operations *(high confidence).* Climate change will *likely* affect coastal sustainable development. On the one hand, energy related infrastructure will become widespread, impacting land use and pollution levels. On the other hand, the distribution of sediments over the coastal regions will be highly affected by environmental changes *(high confidence).* {2.5.2}

The Mediterranean coast is the world's leading tourism destination, and the past projections included very optimistic development *(high confidence).* However, the COVID-19 pandemic and the growing geopolitical conflicts caused a very severe decline (up to 80%) and the whole sector is suffering from uncertainties *(low confidence).* {2.5.2}

With the increasing use of freshwater and the expected increase of aridity, desalination for drinking water, livestock and agricultural use is important and it is *very likely* that it will continue to gain importance on the coast of Algeria, Egypt, Israel, Italy, Malta, and Spain. {2.5.2.3}

The catch potential of fish and invertebrates on the eastern and southern Mediterranean coasts is projected to decline and even to become extinct under the most pessimistic scenario (RCP8.5). Some species will be included in the Red List of the International Union for Conservation of Nature (IUCN) and others are expected to become extinct *(very high confidence).* {2.5.2.4}



2.1 Introduction

A driver is any natural or human-induced factor that directly or indirectly causes a change in a system (IPCC 2021a). Most drivers, especially those related to climate change, pollution, or human activities, have been presented and discussed in the latest IPCC AR6 report of the Working Group I (IPCC 2021b) and the MedECC First Mediterranean Assessment Report (MAR1, MedECC 2020). This Chapter is mainly grounded on them, but with some updating and additional items. Drivers may operate singularly, or in conjunction, and may generate negative feedback loops, where drivers can be either the cause or consequence of changes. The aim is to summarise the key drivers that govern the coastal climate, the sea level, and the coastal ecosystem of the Mediterranean, and are a prerequisite to understanding what is explained in the next Chapters. This Chapter considers a comprehensive set of drivers relevant for coastal communities, with special attention to projections and their potential synergisms with other natural or anthropic drivers. The spatial and temporal combination of concurrent drivers and/or meteorological conditions may amplify each other and lead to even greater secondary impacts with unprecedented social, ecological and economic consequences (Bevacqua et al. 2021; Xoplaki et al. 2023).

The identification of drivers helps to identify critical issues, predict changes and hazards, and assess risks *(Chapter 3)*. On this basis, it will be possible to adopt measures to reduce potential damage to ecosystems and human systems, or to adapt them to climate change *(Chapter 4)*, as well as to plan sustainable development pathways *(Chapter 5)*. Therefore, the presentation of the drivers, their long-term trends, and related future scenarios, has been organised to produce a comprehensive overview.

2.2 Climate and geological drivers

2.2.1 Air temperature

There is robust evidence that the Mediterranean region has significantly warmed basin-wide. The annual mean temperature of the air in the Mediterranean region is +1.54°C higher than the 1860-1890 preindustrial level for land and sea areas, that is +0.4°C more than the global average *(observed data)* (Cherif et al. 2020). The Mediterranean Sea's surface temperature has been

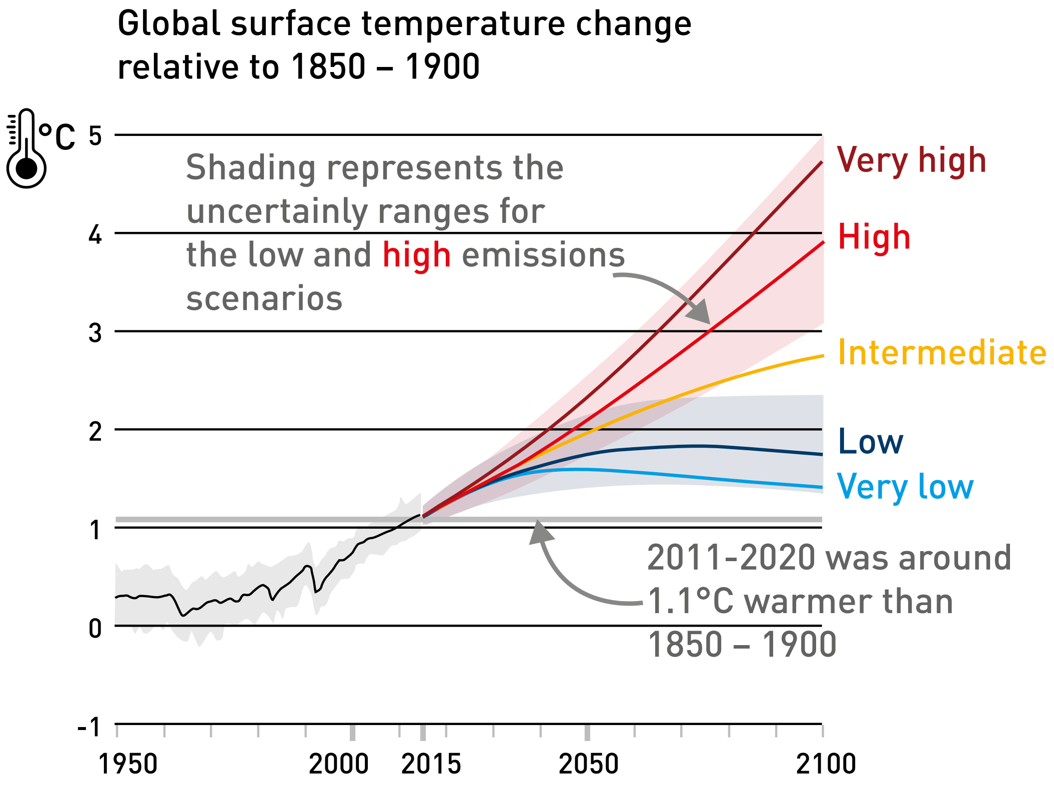


Figure 2.1 | Projected global surface temperature change relative to 1850 – 1900. Source: IPCC (2023).

characterised by a long-term positive trend of about +0.86°C per century since the preindustrial period *(observed data),* in conjunction with a multidecadal periodicity (~70 years) (Axaopoulos and Sofianos 2010; Rivetti et al. 2017; Darmaraki et al. 2019a; Pastor et al. 2020).

Over the 20th century, climate reconstructions, ground-based observations, reanalysis and remote-sensing datasets all corroborate the transition to warmer conditions, and that warming has accelerated during the last decades, with significant positive trends of the order of +0.1°C to +0.5°C per decade (Lionello and Scarascia 2018; Bilbao et al. 2019). All studies, and IPCC (2021b) as well, present a strong consensus that present-day warming is robust throughout the Mediterranean region *(high confidence),* although the extent and level of significance of the observed temperature trends along the Mediterranean coast vary, depending on geographical position, type of data, season, and period of analysis. Air and sea temperature and their extremes are *likely* to continue to increase more than the global average *(high confidence)* (Boberg and Christensen 2012). The projected annual mean warming on land at the end of the century is in the range of +0.9°C to +5.6°C compared to the last two decades of the 20th century, depending on the emission scenario *(high confidence)* (Boberg and Christensen 2012; Cos et al. 2022). According to map from MedECC (2020) and IPCC (2023), the most severe warming will *likely* occur on the mountain and the coastal areas of the easternmost Mediterranean Sea, for example Egypt, Israel, Lebanon, and Syria *(high confidence).*

The Mediterranean Basin is among the most responsive regions to global (Seneviratne et al. 2021). In the future, widespread warming will *almost certainly* occur in the Mediterranean in the 21st century *(high confidence).* There are strong indications and a general consensus that regional warming will continue faster than the global average and at the end of the century it will exceed the global mean value by +20% on an annual basis and +50% in summer *(high confidence).* According to projections for the RCP8.5 scenario[21], summer daily maximum temperature is expected to increase up to +7°C by the end of the 21st century in comparison with the recent past (Lelieveld et al. 2016; Lionello and Scarascia 2018; Bilbao et al. 2019). As shown in *Chapter 1*, *Table 1.1*, making reference to the 1850–1900 period, for the Mediterranean coasts, the IPCC interactive Atlas (Gutiérrez et al. 2021) projected a temperature increase of +1.6°C to +2.7°C for the medium term, and +1.6°C to +3°C for the long term, for the SSP1-2.6 low emissions scenario *(very likely)* and values up to +2.3°C to +3.6°C for the medium term, and +4.2°C to +6.8°C for the long term, for the SSP5-8.5 very high emissions scenario *(very likely).*[22]

Unusual and persistent hot weather is expressed in terms of heat waves[23] (HW). Projected changes in extreme temperature indicators suggest that both the frequency and the severity of heat waves will increase *(very high confidence).*

Daytime temperatures are expected to increase more than night-time temperatures, indicating an increase in the amplitude of the daily temperature range. The minimum temperature of the day is recorded at the end of the night, and a day in which the minimum temperature exceeds 20°C is said to have a tropical night[24] (TN). The number of TNs has increased over most Mediterranean locations including Iberia, North Africa, Italy, Malta, Greece, Anatolia, and the Levant *(very high confidence).* The number of TNs *will likely* increase by more than +60% in these parts of the Mediterranean. The increase

---

[21] Representative Concentration Pathways (RCP) are greenhouse gas concentration trajectories (not emissions) used for the 5th phase of the Coupled Model Intercomparison Project (CMIP5) and labelled in line with a possible range of radiative forcing values in the year 2100: 2.6, 4.5, 6.0, and 8.5 W m^{-2} respectively. These correspond to one stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and one scenario with very high GHG emissions (RCP8.5).

[22] Shared Socioeconomic Pathways (SSP) are cited as defined in IPCC AR6 based on future greenhouse gases (GHG) emissions, labelled after the SSP narrative and associated radiative forcing values in the year 2100 (1.9, 2.6, 4.5, 7.0, and 8.5 W m^{-2}). SSP1-1.9 - very low GHG emissions and SSP1-2.6 – low GHG emissions (CO_2 emissions reduce to net zero in the 2050s), SSP2-4.5 – intermediate GHG emissions (CO_2 emissions remain around current levels until 2050, then falling but not reaching net zero by 2100), SSP3-7.0 – high GHG emissions, and SSP5-8.5 – very high GHG emissions (CO_2 emissions roughly double from current levels by 2100 and 2050, respectively).

[23] A heat wave (HW) is broadly defined as a 'marked warming of the air, or the invasion of very warm air, over a large area; it usually lasts from a few days to a few weeks' by the International Meteorological Vocabulary (WMO 1992) and more recently as 'a period of abnormally hot weather, often defined with reference to a relative temperature threshold, lasting from two days to months' (IPCC 2021) and 'a period of marked and unusually hot weather persisting for at least two consecutive days' (WMO 2023).

[24] Tropical night (TN) is defined as a 'night in which the air temperature does not fall below 20°C' (WMO et al. 2009).

in high temperature extremes will especially occur in summer, with +4°C global warming. Almost all nights will be warm and there will be no cold days *(medium confidence)* (Lionello and Scarascia 2020). Satellite investigations made on cities of the Iberian Peninsula have found no evidence that the effect of urban heat islands on the coasts is more enhanced than inland, but that the result may change with the characteristics of the cities, i.e. the choice of the case studies *(low confidence)* (Hidalgo García et al. 2022).

An unusually high and persistent sea water temperature is expressed in terms of marine heat waves[25] (MHW). In response to increasing greenhouse gas forcing, MHW are projected to further increase in frequency, duration, spatial extent and intensity (maximum temperature) *(very high confidence).* Climate models project increases in the frequency of MHW by 2081–2100, relative to 1850–1900, by approximately 20 times under RCP2.6 and 50 times under RCP8.5 *(medium confidence)* (IPCC 2023). More particularly, MHW are expected to become stronger and more intense under RCP4.5 and RCP8.5 than RCP2.6. By 2100 and under RCP8.5, simulations project at least one long-lasting MHW every year, up to three months longer, about 4 times more intense and 42 times more severe than present-day events. They are expected to occur from June to October and to affect the entire basin at peak *(medium confidence).* Until the mid-21st century, MHW characteristics are estimated to increase independently of the choice of the emission scenario, the influence of which becomes more evident by the end of the period. Further analysis reveals different climate change responses in certain configurations, more *likely* linked to their driving global climate model rather than to the individual model biases *(low confidence)* (Darmaraki et al. 2019a).

2.2.2 Precipitation

The synthesis made by IPCC (2023) is that precipitation will *likely* decrease in most areas by −4 to −22%, depending on the emission scenario *(medium confidence).* Rainfall extremes will *likely* increase in the northern part of the Mediterranean coast, as well as in Sicily, where a significant increasing trend has been observed *(high confidence)* (Treppiedi et al. 2021). Analysis of long-term rainfall time series showed statistically significant increasing trends in short duration precipitation occurrence, and rainfall rates, suggesting a possible future scenario with a more frequent exceedance of threshold triggering values, and an increase of landslide risk *(high confidence)* (Roccati et al. 2020). Droughts will become more prevalent in many areas, especially in the easternmost and southern Mediterranean coasts *(high confidence)* (MedECC 2020; UNEP/MAP and Plan Bleu 2020; Ali et al. 2022).

Across the Mediterranean, observed precipitation trends show pronounced spatial variability, increasing or decreasing depending on the time period and season considered. Several studies have assessed changes in interannual variability of precipitation, but the extent and the pattern of precipitation decreases widely vary across models, even with contrasting trends *(low confidence)* (Peña-Angulo et al. 2020; Vicente-Serrano et al. 2021). Model projections suggest that global warming will further increase the existing difference in intensity of precipitation and hydrological extremes between northern and southern Mediterranean areas *(high confidence).* The projected increase in dry spell length is greater in the southern than in the northern Mediterranean *(medium confidence)* (Lionello and Scarascia 2020). In the total annual budget, the contribution of extreme daily rainfall is projected to increase throughout the Mediterranean region. This increase is expected to be strongest in North Africa and particularly in the Maghreb region *(high confidence)* (Zittis et al. 2021). A robust and significant precipitation decline is projected over large parts of the region during summer by the end of the century and for the high emission scenario (−49 % to −16 % for CMIP6 (Coupled Model Intercomparison Project Phase 6[26]) and −47 % to −22 % for CMIP5) *(high confidence)* (Cos et al. 2022). Future projections made by Zittis et al. (2021) indicate a strong northern/southern Mediterranean gradient, with significant, decreasing

---

[25] Marine heat wave (MHW) is defined as a 'period of five or more days in which ocean temperatures are above the 90th percentile, that is in the top 10% of recorded figures for that region at that time of year' (WMO 2023) as well as 'a period during which water temperature is abnormally warm for the time of the year relative to historical temperatures, with that extreme warmth persisting for days to months.' (IPCC 2021).

[26] https://wcrp-cmip.org/

trends in the magnitude of daily precipitation extremes in the south and the Maghreb region (up to −10 mm decade^{-1}) and less profound, increasing trends in the north *(high confidence).*

At a local scale, the extreme rainfall trend can increase by a factor of 2 compared to the regional assessment. In the future climate, characterised by an increase of about 2°C in global temperature, extreme daily rainfall (95th percentile) is expected to increase by about +10% relative to the current level *(medium confidence).* This is the same order of magnitude as the increase observed at regional scale in the recent past (Molinié et al. 2016). The 100-year extremes have no specific trend or preferential areas *(medium confidence)* (Peña-Angulo et al. 2020; Vicente-Serrano et al. 2021). The contribution of the wettest day per year to the annual total precipitation is expected to increase (+5% to +30%) throughout the whole Mediterranean region. The 50-year daily precipitation extremes are projected to strongly increase (up to +100%) throughout the whole region *(medium confidence)* (Zittis et al. 2021). IPCC (2023) specifies that there is low agreement on heavy precipitation change across the Mediterranean *(low confidence).*

2.2.3 Atmospheric circulation

The proximity to the Atlantic and Indian Oceans and the surrounding massive land areas, places the Mediterranean area at the crossroads of many global climate patterns and processes of tropical and extratropical origin. The projected expansion of the Hadley Cell will shift the mid-latitude westerlies and storm tracks northward, thus reducing storminess *(medium/high confidence)* (D'Agostino et al. 2020) and precipitation *(medium confidence).* The Mediterranean could be influenced by additional local circulation anomalies, leading to pronounced changes in precipitation patterns *(medium confidence)* (D'Agostino and Lionello 2020).

Winds and wind waves

Surface wind speeds and their changes across different temporal and spatial scales are governed by driving and drag forces, whose individual contributions are difficult to estimate and disentangle. In addition, observation-based studies of winds across the Mediterranean are less frequent than for other meteorological variables. Wintertime large-scale circulation has exhibited a long-term trend toward increased sea-level pressure and anticyclonic circulation over the Mediterranean, with multi-decadal variability *(very high confidence).* During summer, a possible decline in sea-level pressure over North Africa and the southern Mediterranean is expected *(medium confidence).* In most regions, wind trends have been found to be non-monotonic over the past decades, which complicates the identification of clear long-term patterns *(very low confidence).*

Despite the uncertainties in future projections, there is a general agreement for a limited wind speed reduction across most of the Mediterranean, with the exception of the Aegean Sea and northeastern land areas *(medium confidence),* while changes in the local winds may have more complex responses involved, depending on the changes in their underlying feedbacks. Over the western Mediterranean, Mistral wind is projected to have small changes, and Tramontane a significant decrease in frequency. Over the Adriatic Sea, in winter, the occurrence of Bora wind is projected to increase in frequency, while the frequency of Sirocco is expected to decrease. Over the Aegean Sea, Etesian winds are expected to increase in speed *(high confidence)* (Belušić Vozila et al. 2019; Dafka et al. 2019; Ezber 2019).

Since sea waves are primarily driven by winds, high waves are present across most of the Mediterranean Sea and tend to reach the highest values where strong winds combine with long fetches. Wind waves are driven by wind and continue their motion by inertia, until they break on a coast exposed to the wind, thus causing coastal erosion. Compared to the Atlantic, in the Mediterranean Sea, the mean wave heights (1 m to 1.5 m) are lower, and the periods (5 s to 6 s) shorter, with relevant spatial variability due to the complex orography and coastline surrounding the basin *(high confidence)* (Menendez et al. 2014).

The coasts most exposed to the risk of high waves are mainly located in the central and western Mediterranean, and in particular the Gulf of Lion, on the southern coast of France, where the effect is most pronounced (Patlakas et al. 2021). It has been evaluated that 71.4% of the Mediterranean coast is exposed to significant wave heights that have a 100-year return period higher than 5 m, and

22.4% of the coast to waves higher than 9 m. These values increase for islands, where 93.2% of the coast is exposed to significant wave heights higher than 5 m and 30% higher than 9 m *(medium confidence)* (Toomey et al. 2022).

The highest waves (5 m to 6 m) extend from the Gulf of Lion to the southwestern Sardinia through the Balearic Sea and are sustained southwards approaching the Algerian coast *(high confidence)* (Lionello et al. 2017). They result from northerly winds dominant in the western Mediterranean Sea (Mistral or Tramontana) that become stronger due to orographic channelling, and act over a large area, breaking on the northern and western coasts of Corsica, Sardinia, and Balearic Islands. In the Ionian Sea, the northerly Mistral wind is still the main cause of high waves (4 m to 5 m) that will break on the eastern coasts of Greece and northern Africa. In the Aegean and Levantine Seas, high waves (4 m to 5 m) are caused by the northerly Bora winds (affecting the western coasts), prevalent in winter, and the northerly Etesian winds (affecting the southern coasts), prevalent in summer. In general, northerly winds are responsible for most high waves in the Mediterranean Sea *(high confidence)* (Obermann-Hellhund et al. 2018; Dafka et al. 2019; Ezber 2019). Model projections suggest that future changes in waves will be determined by changes in the wind field over the Mediterranean Sea *(high confidence).* A number of studies point towards a generalised reduction of the mean significant wave height field over a large portion of the Mediterranean Sea, especially in winter *(high confidence)* (Hueging et al. 2013; Tobin et al. 2015; Moemken et al. 2018). For all the Mediterranean Sea, during spring, the projected changes of wave directional spectra present an overall robust decrease in the predominant wave systems, in agreement with previous studies depicting a decrease in the significant wave height. Nonetheless, a robust increase in other less energetic frequencies and directions is observed for both mid-century and end-of-century conditions throughout the Mediterranean Basin *(medium-high confidence)* (Lira-Loarca and Besio 2022).

Extreme waves are expected to decrease in number and intensity, although there is no consensus on whether very large extreme events, associated with very strong winds, would also decrease *(low confidence).* A simulation done with a set of seven models under emission scenario RCP8.5 across the Mediterranean Basin has shown, on average, a decreasing trend of significant wave height and mean period, while the wave directions may be characterised by a slight eastward shift *(medium confidence)* (De Leo et al. 2021).

2.2.4 Cyclones affecting Mediterranean coasts

Certain hazards may occur occasionally, independently from other challenges, or may occur in temporal sequence, or may operate synergistically. Their combination and clustering may constitute a hazard greater than the sum of the individual contributions, and Mediterranean cyclones are a typical example. The sea level rise driven by climate change, combined with changes in storminess, will *likely* lead to increased clustering of storm surges, waves, and high sea levels, further exacerbating the impacts of flooding and erosion (Fox-Kemper et al. 2021). The Mediterranean is one of the main cyclogenetic areas of the world, and Mediterranean cyclones are related to a number of effects, for example episodic events affecting sea level anomalies, or generating meteotsunamis, high waves, and flooding (see *Chapter 3*).

2.2.4.1 Cyclogenetic activity

The northwestern Mediterranean, North Africa, and the north shore of the Levantine Basin are the areas most affected by cyclogenetic activity (Miglietta 2019). When cyclogenesis occurs in the western Mediterranean, either positive or negative sea level anomalies[27] may be generated. Atlantic cyclones mainly produce positive anomalies in the western Mediterranean. Cyclogenesis in the eastern Mediterranean generates positive sea level anomalies on the easternmost Mediterranean coast. Cyclogenesis over North Africa generates positive anomalies on the African coast and negative anomalies on the eastern Mediterranean and northern Aegean coasts (Lionello et al. 2019). High correlations between deep depressions and sea level

---

[27] Elevations above sea level (i.e. increase) are positive and elevations below sea level (i.e. decrease) are negative.

anomalies have been observed in several parts of the northern Mediterranean coasts (Gulfs of Valencia and Lions, Ligurian and northern Adriatic Seas). They are followed by mid-latitude areas around Corsica, Sardinia, the mid-zonal Italian Peninsula and the Adriatic, and the northern Aegean Sea. The influence of deep depressions on storm surges is lower for Sicily, southern Italy, Peloponnese, Crete, the southern Aegean archipelago, and Alboran Sea *(high confidence)* (Makris et al. 2023).

2.2.4.2 Mediterranean cyclones

Long-term changes, at interannual and longer timescales, in extreme sea levels are primarily driven by changes in mean sea level (Woodworth et al. 2019). However, variations in extreme sea levels unrelated to mean sea level variability have also been identified in tide gauge records at an hourly scale (Wahl and Chambers 2015; Marcos and Woodworth 2017) and been linked to storminess and changes in storminess (Pérez Gómez et al. 2022). Mediterranean cyclones are responsible for severe surges, but flooding frequency and flooding water depth depend on a complex combination of factors including coastal morphology, vertical land motions and local sea level. The local sea level may be amplified by waves, wind, intense precipitation, currents and other factors. In the Mediterranean, higher values are found in the northern Adriatic (between 150 cm and 200 cm) while in the rest of the region they vary between 20 cm and 60 cm (Marcos et al. 2009). If the corresponding annual mean level is extracted from the extreme sea levels, a reduction in trends at most stations is obtained, which leads to the conclusion that much of the change in the extremes is due to a change in the mean sea level *(high confidence)* (Menéndez and Woodworth 2010). The future sea level rise will *very likely* become the dominant factor for an increased frequency and intensity of coastal floods (Camuffo et al. 2017; Lionello et al. 2017; Vousdoukas et al. 2017; Soto-Navarro et al. 2020; Camuffo 2022a, 2022b, 2023; Reale et al. 2022). The highest sea surface elevations are found on the coasts of the northern Adriatic Sea (caused by storm surges induced by south-easterly wind setup effect) and in regions with wide shallow continental shelves (Gulf of Gabes, Syrte, Nile delta, Gulf of Lion, and the Spanish eastern coasts) that favour wind and wave setup *(high confidence)* (Toomey et al. 2022). The rise in frequency of concurrent extremes in precipitation and meteorological tides is particularly evident for coasts in the northern Mediterranean *(high confidence)* (Bevacqua et al. 2020). Steric expansion and storminess are shown to be contrasting factors; in the next decades, wave and storm surge maxima will decrease while the thermosteric expansion will increase the mean sea level. To a large extent, these two effects will offset each other, so that their superposition will increase/decrease the maximum water level along two comparable fractions of the coastline (about 15% to 20%) by the mid-21st century *(medium confidence)* (Lionello et al. 2017). However, at a multi-decadal timescale, there is an offset of −10 cm per century between observed and modelled thermosteric sea level over the historical period and modelled thermosteric sea level over this century for the same rate of change in global temperature. The mass addition across the Gibraltar Strait to the Mediterranean Sea will *likely* become the dominant factor and determine an increase in the maximum water level along most of the coast *(medium confidence)* (Lionello et al 2017). Analyses of tide gauge data have revealed an increase in the magnitude and duration of extreme sea levels in the region in recent decades, caused by the rise in the relative mean sea level *(very high confidence)* (Lionello et al. 2021; Zanchettin et al. 2021; Camuffo 2022a, 2022b, 2024).

Although the number of cyclones has *likely* decreased, this reduction is not statistically significant (Romera et al. 2017; González-Alemán et al. 2019). The projected changes in cyclone hazards toward the late 21st century show a limited agreement in terms of magnitude and even sign of the projected changes along most of the coastal regions *(low confidence)* (Toomey et al. 2022).

Future projections under the RCP8.5 scenario, estimate that the Alboran Sea, the Gulfs of Gabes, Alexandretta, and the Aegean Sea's coasts will be further increasingly influenced by deep depressions *(medium confidence)*. A general consensus is that deep depressions and storm surges would probably cause mid-to-high sea elevations on the Aegean Sea, Ionian Sea, Gulf of Lions, Valencia, Gabes; the highest will be reached on the northern Adriatic and the Ligurian Sea. In the coastal regions of northern Italy, however, intense local wind forcing (i.e. Sirocco) might play a more significant role in the formation of high storm surges *(high confidence)* (Makris et al. 2023).

The predicted northward shift of storm tracks will cause a decreasing trend in storminess *(medium confidence)*, especially over areas where the main driving factor of extreme events is the atmospheric pressure pattern over the Mediterranean, and its dynamics (D'Agostino et al. 2017; Grise et al. 2019). The extreme sea surface elevations are predicted to increase in several Mediterranean sub-regions, such as the southern Adriatic, Balearic and Tyrrhenian Seas. In the Aegean Sea, low-pressure systems are predicted to be the main drivers of high surges, while in the Adriatic Sea, high surges will be *likely* driven by adverse wind conditions *(medium confidence)* (Androulidakis et al. 2015).

For a moderate-emission scenario (RCP4.5), the magnitude of 1-in-100-year water height values on the northern Adriatic coast is projected to increase by +12 cm to +17 cm by 2050 and +24 cm to 56 cm by 2100. Local subsidence (which is not included in the above estimates) will further contribute to the future increase in extreme water heights. On the northern Adriatic coast, for a high-emission scenario (RCP8.5), with respect to present levels, these values are projected to increase by +26 cm to +35 cm by 2050 and by +53 cm to +171 cm by 2100 and are subject to continue increasing thereafter *(medium confidence)* (Lionello et al. 2021)

Medicanes

A sub-group of hybrid depressions of extratropical cyclogenesis is constituted of so-called medicanes, that is Mediterranean hurricanes or tropical-like cyclones. The highest waves induced by medicanes are found in the central and the southwest part of the western Mediterranean, while the greatest storm surges are found in the Adriatic Sea and regions characterised by wide and gently sloping continental shelves (Toomey et al. 2022). In Sicily, coastal flooding due to medicanes is more frequent than flooding caused by other storms (Scicchitano et al. 2021). In the recent past, no strong trends have been identified *(medium confidence).* The projected effect of climate change on medicanes indicates a decreased frequency and a tendency toward a moderate increase in intensity *(medium confidence)* (Gaertner et al. 2007; E. Romero et al. 2013; R. Romero and Emanuel 2013; Tous and Romero 2013; Cavicchia et al. 2014; Walsh et al. 2014; Romera et al. 2017; González-Alemán et al. 2019; Toomey et al. 2022).

2.2.4.3 Meteotsunamis

Meteotsunamis are atmospherically induced destructive long waves in the tsunami frequency band, formed by storm systems moving rapidly across the sea, such as a squall line, and their development depends on several factors such as the intensity, direction and speed of the disturbance as it travels over the sea. The initial meteorological forcing may be related to atmospheric gravity waves, frontal passages, squalls, pressure jumps, and other types of atmospheric disturbances. On many occasions the forcing, being of mesoscale nature, has been related to some favourable synoptic pattern, which has been clearly established (Ramis and Jansà 1983; Monserrat et al. 1991). The atmospheric source normally generates barotropic ocean waves in the open ocean which after being amplified near the coast through some resonance mechanism (Proudman, Greenspan, shelf, harbour) can affect coasts in a similar damaging way as seismic tsunamis. However, due to the resonance mechanism required, their catastrophic effects are restricted to some specific bays and inlets (Monserrat et al. 2006).

Meteotsunamis have been traditionally studied much more in the Mediterranean than in the rest of the world. This is surely related to the micro-tidal nature of most of the Mediterranean Sea (e.g. Tsimplis et al. 1995). Due to the small tides, coastal infrastructures along the Mediterranean are generally not adapted to accommodate large sea level changes and meteotsunami damages and flooding are potentially worse in the Mediterranean in comparison to other macro-tidal coasts of the world (*see Chapter 3, Section 3.2.4.2*).

It seems that no significant changes in meteotsunamis are projected under RCP2.6 and RCP4.5 scenarios. However, they are *likely* to increase in RCP8.5, where the increase matches the spring–summer season when meteotsunamis reach their maximum intensity *(medium confidence)* (Vilibić et al. 2018 2021).

2.2.4.4 Cyclonic precipitation

On the coasts, the intense precipitation that on some occasions is associated with cyclones, may generate flash floods of low-lying areas, coastal erosion, raging torrents, or invade the urbanised areas causing a significant loss of human lives (see *Chapter 3, Section 3.2.3*).

The origin and track of cyclones producing intense precipitation differ in different areas. For the end of the 21st century, models project an overall weakening of the systems crossing the Mediterranean region, and in particular a robust decrease in the number and intensity of cyclones crossing the central part of Italy, Tyrrhenian Sea, parts of the Anatolian Peninsula, Balkan area and North Africa. A significant increase in cyclone-related precipitation and wind intensity in the central part of the Mediterranean region is also expected *(medium confidence).* Over most of the Mediterranean, the decrease in accumulated precipitation in winter will be driven by the decrease in the number of cyclones crossing the area and will be only partially compensated by the increase in the intensity of the rainy events associated with each cyclone. In the eastern Mediterranean, the drier conditions observed in winter will be driven by both the decrease in the number of cyclones and the intensity of each rainy event *(medium confidence)* (Reale et al. 2022a). Conversely, models predict an opposite change in precipitation and wind intensity in the south-eastern part of the region. Both signals are spatially coincident with the decrease of the number of cyclones. In winter, an overall decrease in total accumulated precipitation over most of the Mediterranean region is expected. For the end of the 21st century, models are consistent in predicting a decrease in the number and an overall weakening of cyclones moving across the Mediterranean *(high confidence),* but the magnitude of the projected changes varies considerably across models, especially over the Ionian Sea and Iberian Peninsula *(low confidence)* (Reale et al. 2022a).

2.2.5 Sea water temperature, salinity, and acidification

2.2.5.1 Sea water temperature

The water temperature of the Mediterranean Sea is unevenly distributed, with the higher temperature values on the easternmost side and North Africa. Direct observations and numerical simulations show that the Mediterranean waters are becoming warmer *(very high confidence).*

Satellite data since the 1980s show spatially inhomogeneous warming rates of the sea surface between +0.29°C and +0.44°C per decade, stronger in the eastern Mediterranean, and that over the last two decades, mean MHW frequency increased by +40%, and duration increased by +15% *(high confidence)* (CEAM 2019, 2021; Darmaraki et al. 2019a; Pisano et al. 2020; Ibrahim et al. 2021). Sea surface warming has not been uniform, but mostly bimodal with stronger trends in the eastern Mediterranean (Adriatic, Aegean, Levantine and North-East Ionian Seas), while a spot in the Ionian Sea has warmed 50% less than the Mediterranean average (Dell'Aquila et al. 2018). In the Mediterranean Sea, periods of abnormally warm sea surface, also called 'marine heat waves' have become more frequent, more intense, spatially more extended and more severe over recent decades (Oliver et al. 2018; Darmaraki et al. 2019a).

Model projections suggest significant warming of the surface waters of the Mediterranean Sea *(very high confidence)* (Alexander et al. 2018; Darmaraki et al. 2019b). The warming rate depends on both the temporal horizon and the greenhouse gas emission scenario *(very high confidence).* For the large thermal inertia of water, sea warming will generally remain below that of the air over the surrounding land *(high confidence),* probably causing an increase in land-sea temperature contrast. Compared to the end of the 20th century, the annual mean basin sea surface temperature is expected to increase from +0.6°C to +1.3°C before the mid-21st century, and from +2.7°C to +3.8°C at the end of the 21st century period under the pessimistic RCP8.5 scenario and from +1.1°C to +2.1°C for the medium RCP4.5 scenario *(medium confidence)* (Darmaraki et al. 2019b). Future warming will be roughly homogeneous in space *(medium confidence)* with the Balearic Sea, the north Ionian Sea, the north-eastern Levantine Sea and the Adriatic Sea identified as potential hotspots of maximum warming *(low confidence).* At the end of the 21st century, water masses deeper than 600 m may warm between +0.03°C and +1.38°C (Soto-Navarro et al. 2020). Warming is not projected to be constant all year round. Stronger warming is expected in summer and weaker warming in winter, resulting in a substantial increase in warm extremes and a weaker decrease in cold extremes *(medium* to *high confidence)* (Alexander et al. 2018; Darmaraki et al. 2019b; Soto-Navarro et al. 2020).

2.2.5.2 Salinity

Coastal gradients of soil salinity are established from the seashore to inland areas, and vascular plant richness and diversity are influenced by the distance from the sea. Soil salinity is strongly affected by the type of soil and habitat, which is average at the rocky coasts and negligible at the sandy shores (Maccioni et al. 2021).

An increase in salinity has been projected in both the RCP4.5 and RCP8.5 scenarios in the intermediate layer at the basin scale and in both the eastern and western sub-basins of the Mediterranean. The variation in salinity is strongly dependent on the emission scenario, with more intense anomalies — both negative and positive — obtained under RCP8.5 conditions *(medium confidence).* For example, the salinity in the surface layer at basin scale and in the eastern Mediterranean is characterised by a decrease between 2020 and 2050 followed by a constant increase until the end of the 21st century. Conversely, after 2050, the western basin shows a freshening of the surface layer with respect to the beginning of the century (Soto-Navarro et al. 2020; Reale et al. 2022b). Direct observations and numerical simulations show that deep Mediterranean waters are becoming saltier *(high confidence).* The future evolution of sea surface salinity of the Mediterranean Sea remains largely uncertain as its sign of change *(very low confidence).* Any change will *likely* be spatially and temporally inhomogeneous due to the primary role of the river and near-Atlantic freshwater inputs *(medium confidence)* (Soto-Navarro et al. 2020).

Across the Strait of Gibraltar, near-Atlantic warming will *likely* increase the net transport of water mass and heat towards the Mediterranean Sea. However, the future evolution of the net salt transport across the strait is unclear, because it depends on the salinity change in the near-Atlantic Ocean surface layer entering the Mediterranean Sea. Consequently, it is unclear whether the salt transport from the Atlantic will increase or decrease *(low confidence)* (Soto-Navarro et al. 2020).

For the surface waters of the Mediterranean, model projections suggest that, for the end of the 21st century, basin-scale surface salinity anomalies range from −0.18 psu to +0.16 psu for the pessimistic RCP8.5 scenario and from −0.25 psu to +0.25 psu for the RCP4.5 scenario. However, a surface salinity increase in the eastern Mediterranean Basin is more *likely* than not, whereas the western basin is highly uncertain. For the deeper layers, the rates of warming and salinity changes are very uncertain. At the end of the 21st century, the salinity of water masses deeper than 600 m may increase or decrease with a large uncertainty range, depending on the model (−0.05 psu to +0.51 psu) *(low confidence)* (Soto-Navarro et al. 2020).

2.2.5.3 *Acidification and deoxygenation*

Excessive nutrient discharges and associated microbial bloom are the main reasons for coastal hypoxia and acidification. Extremely high $p\mathrm{CO}_2$ values have been reported as a result of algal bloom, eutrophication and mucilage in hypoxic coastal areas, which may further exacerbate the increased $p\mathrm{CO}_2$ levels induced by anthropogenic CO_2 emissions. The Mediterranean is vulnerable on the northern coasts to eutrophication and associated coastal acidification due to the excessive loads of nutrients from sewage effluents, river fluxes, agriculture and aquaculture fertilisers, and industrial facilities (Karydis and Kitsiou 2012; Kapsenberg et al. 2017).demonstrated a pH decline in seawater (-0.0028 ± 0.0003 $\mathrm{pH_T}$ y^{-1}) on the northwestern coast in the long term, which is more rapid than open oceans. On the other hand, there is a growing trend in nutrient input along the eastern and southern Mediterranean coasts (see *Section 2.4.1*), which will exacerbate the coastal acidification on the eastern and southern coasts *(medium confidence).*

The change in pH is well correlated with dissolved inorganic carbon. Human-caused CO_2 on the sea surface results in an increase in seawater H+ ions, and a decline in carbonate ion concentration. Due to this phenomenon called ocean acidification, the acidity in surface seawater has increased by about +30% (i.e. −0.10 to −0.15 decrease in pH) since the industrial revolution. Average in situ pH decline is −0.002-unit y^{-1} in world oceans (IPCC 2023), similar to the Mediterranean Sea (Solidoro et al. 2022).

Several studies have reported a significant decline in the pH of the Mediterranean Sea over the last few decades (e.g. Touratier and Goyet 2011; Palmiéri et al. 2015; Flecha et al. 2019; Solidoro et al. 2022). The decrease of pH is between −0.055 and −0.156 pH unit in surface seawater since the industrial revolution indicates that all Mediterranean Sea waters are already acidified (Hassoun et al. 2015). Wimart-Rousseau et al. (2021) reported a significant annual decrease in the surface seawater pH_T (−0.0024 ± 0.0004 pH unit) in the northwestern Levantine Basin. Since pH trends offshore and on the coast are similar in the Mediterranean Sea, acidification is projected to continue both offshore and on the coast (virtually certain) (Seneviratne et al. 2021; Hassoun et al. 2022). pH will decrease between −0.25 and −0.46 pH units in Mediterranean surface waters by the end of this century compared to the pre-industrial era in high CO_2 emission scenarios *(medium confidence)* (Goyet et al. 2016; Hassoun et al. 2022; Solidoro et al. 2022).

Due to diminishing oxygen solubility with rising temperatures, as well as increased water column stratification and eutrophication events, global warming may exacerbate hypoxia in coastal environments. There have been a few reports of oxygen depletion in the Mediterranean Sea, mostly in the area south of Cyprus and the Balearic Islands (EEA 2022b). Approximately 21% of the Mediterranean Sea suffers from hypoxia (2.3% hypoxic: <2 mg oxygen L^{-1}, 18.3% moderate hypoxic: 2–6 mg oxygen L^{-1}) (EEA 2022b). The increasing trend in warming, nutrient discharges and associated eutrophication is *likely* to expand the extent and intensity of hypoxia in Mediterranean coasts (Reale et al. 2022b).

Projections made for the middle and end of the 21st century under RCP4.5 and RCP8.5 predict changes in the dissolved nutrient contents of the euphotic and intermediate layers of the basin, net primary production, phytoplankton respiration and carbon stock (including phytoplankton, zooplankton, bacterial biomass and particulate organic matter). The projections show uniform surface and subsurface deoxygenation driven by the warming of the water column and by the increase in ecosystem respiration as well as an acidification signal in the upper water column linked to the increase in the dissolved inorganic carbon content of the water column due to CO_2 absorption from the atmosphere and the increase in respiration. The projected changes are smaller near the Strait of Gibraltar (with a maximum decrease of −0.3% under RCP4.5 and −1.2% under RCP8.5) for the exchanges with the Atlantic, and stronger on the eastern Mediterranean coast (with a maximum decrease of −1.2% under RCP4.5 and −3.1% under RCP8.5) *(medium confidence)* (Reale et al. 2022b).

2.2.6 Net hydrological balance: evaporation, precipitation, and river runoff

Overall, the net surface water loss (i.e. the evaporation minus the precipitation over the sea) has increased over most of the Mediterranean surface, mainly due to a decrease in precipitation during the period 1960–1990 and strong evaporation increase since the mid-seventies due to local warming (Sevault et al. 2014; Mariotti et al. 2015; Skliris et al. 2018). Furthermore, the freshwater discharge due to the river runoff has decreased (Lutz et al. 2016; Suárez-Almiñana et al. 2017). An increase in net Gibraltar water flux to compensate for the overall increase in freshwater loss has been derived (Fenoglio-Marc et al. 2013). On the coasts of the easternmost Mediterranean and northern Africa the balance is negative and requires irrigation to mitigate drought and aridity (FAO et al. 2022).

Positive multi-decadal evapotranspiration trends in Mediterranean have been found by several authors (Miralles et al. 2014; Zhang et al. 2016; Zhan et al. 2019), as a consequence of increases in transpiration and interception components, counterbalanced by decreasing soil evaporation *(very high confidence).*

Water stress refers to freshwater withdrawals in proportion to available freshwater resources, taking into account environmental water requirements (the minimum amount of water required to maintain freshwater and estuarine ecosystems and their functioning included in the calculation). A regional-scale investigation conducted for the Mediterranean Basin (Milano et al. 2013) highlighted that 112 million people experience water shortage conditions. The most vulnerable regions are southern Spain, Libya, Tunisia, and the south-eastern Mediterranean (Israel, Lebanon, State of Palestine, and Syrian Arab Republic). By 2050, 236 million people are expected to be living under water shortage *(high confidence).* Severe water stress situations could be mitigated in Albania, Greece and Türkiye but efficiency improvements alone would not be able to reduce water stress in Spain and the southern Mediterranean (UNEP/MAP and Plan Bleu 2020).

In the future, an increase in the net surface water loss by the sea is expected due to a decrease in precipitation and in river runoff and an increase in evaporation *(high confidence)* (Sanchez-Gomez et al.

2009; Elguindi et al. 2011; Dubois et al. 2012; Planton et al. 2012; Adloff et al. 2015; Mariotti et al. 2015). Widespread increase of evaporative demand and a decrease in precipitation explain the drying of the Mediterranean region during recent decades *(high confidence)* (Spinoni et al. 2015, 2017; Gudmundsson and Seneviratne 2016; Stagge et al. 2017; Caloiero et al. 2018; Seneviratne et al. 2021; Ali et al. 2022). Droughts are projected to become more severe, more frequent and longer under moderate emission scenarios, and strongly enhanced under severe emission scenarios *(high confidence)* (Hertig and Tramblay 2017; Lehner et al. 2017; Ruosteenoja et al. 2018; Spinoni et al. 2018; Grillakis 2019; Lionello and Scarascia 2020; Seneviratne et al. 2021).

Several studies show that a combination of reduced precipitation, associated with increased evaporation, will affect the hydrological balance, leading to a decline in water availability, river runoff, and low flows in most locations of the Mediterranean region *(high confidence*) (Droogers et al. 2012; Mariotti et al. 2015; Marx et al. 2018; Thober et al. 2018; Dakhlaoui et al. 2020 2022; Yeste et al. 2021; Ali et al. 2022). River runoff and low flows are expected to decline by −12% to −15% or more *(medium confidence)* (Ali et al. 2022). In North Africa, surface water availability is projected to be reduced by −5% to −40% in 2030–2065 and by −7% to −55% in 2066–2095 from 1976–2005 (Tramblay et al. 2018), with decreases in runoff by −10% to −63% by mid-century in Morocco and Tunisia *(medium confidence)* (Marchane et al. 2017; Dakhlaoui et al. 2020).

2.2.7 Sea level rise and (permanent) coastal submersion

In the recent period, in which Global Sea Level has been monitored by satellite altimetry (1993–2023), in the decade 2013–2022 the rising rate has been +4.68 mm yr^{-1}, which is twice the rate in 1993–2002 at +2.27 mm yr^{-1} *(observed data)* (Cazenave and Moreira 2022). Sea level change is the combination of several processes, including vertical tectonics, glacio–hydro–isostatic signals associated with the last glacial cycle, and changes in ocean volume driven by climate changes. The coastal sea-level, and its change, can substantially differ from open sea-level because near the coast, small-scale processes are combined with the global mean and regional sea-level components (Woodworth et al. 2019). In addition, in many coastal zones, vertical land motions caused by ground subsidence amplify the climate-related sea level rise (SLR) (Wöppelmann and Marcos 2016). The trend is compounded by local effects and interannual and decadal variability that can temporarily mask SLR. During the 20th century, coastal tide gauges around the Mediterranean have recorded SLRs ranging from +0.68 ± 0.37 mm yr^{-1} in Split Rt Marjana to +2.53 ± 0.14 mm yr^{-1} in Venice, both on the northern side of the Adriatic Sea. These different SLRs are explained by vertical land movements. The other stations of the Adriatic Sea show high correlation between them (Pérez Gómez et al. 2022).

The SLR of the Mediterranean has been monitored with 240 tide gauges. The longest series of data, i.e. longer than one century, has been collected by four tide gauges in the Mediterranean (i.e. Trieste and Venice (Italy), Bakar (Croatia), and Marseille (France)) and three in the Black Sea (i.e. Poti, Tuapse, and Sevastopol). The data from all the tide gauge stations have been collected and analysed. (Pérez Gómez et al. 2022). Venice constitutes the longest time series, combining instrumental and proxy data, dating back to 1350. It has been obtained combining tide gauge records (1871 to present) with proxies (i.e. paintings showing the original level of the algae belt, submersion of doors and water stairs of buildings). The observed time series *(Figure 2.2)* shows a continuous increasing trend with +130 cm total rise over 667 years; the initial rate was +1 mm yr^{-1} in 1350, and nowadays (in 2017) it is +3.3 mm yr^{-1} *(observed data)* (Camuffo et al. 2017; Camuffo 2021, 2022a, 2022b). However, it must be specified that around 1mm yr^{-1} is due to local land subsidence. The Venice dataset can be interpolated at the same confidence level by an exponential (that is mathematically representative of sea level rise, rate, and acceleration over time) or a parabola[28] (that gives the rise over time, and the average acceleration over the whole period) (Camuffo et al. 2017; Camuffo 2022a, 2022b). An increasing trend over the past 1000 years is consistent with the multiproxy analysis

---

[28] The quadratic coefficient of the parabola represents ½ of the average acceleration over the whole period. Future projections are based on the trend extrapolation method, which constitutes the projection of a highly inertial system (Camuffo 2022b).

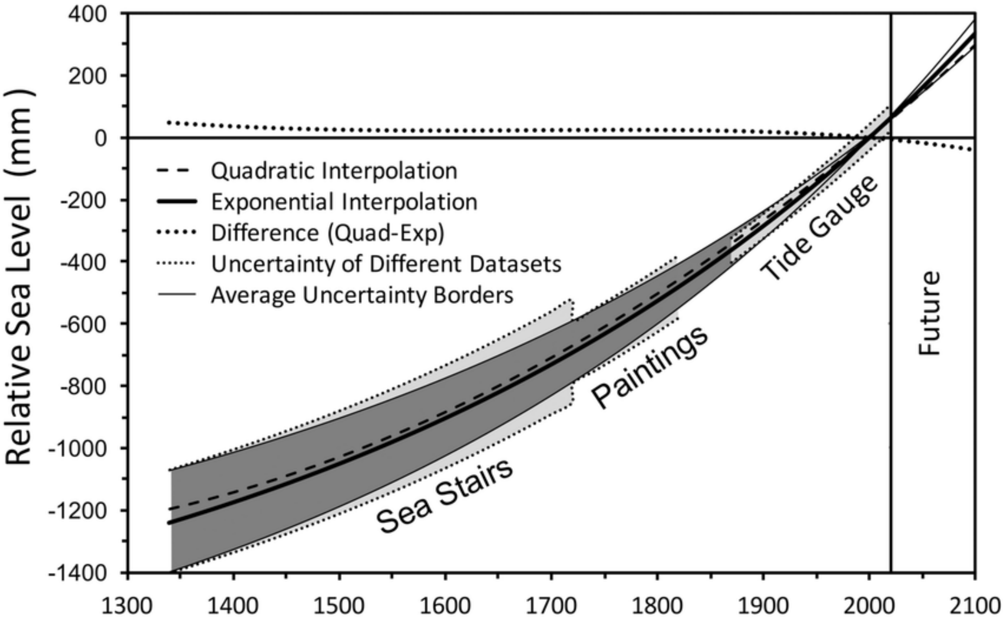


Figure 2.2 | Exponential trend of the relative sea level rise in Venice. Data sources include observations from tide gauge record (1871–2021), Canaletto, Bellotto and Veronese paintings (18th century and 1571) and submersion of the sea stairs used as a proxy (1350–1750). Uncertainties are specified in the legend. The future is based on the trend extrapolation method, which constitutes the projection of a highly inertial system (Camuffo 2022b).

concerning the Gulf of Venice obtained by Kaniewski et al. (2021, 2024). Regional projections including the local and regional processes affecting relative SLR trends in Venice (i.e. local land subsidence), predict the *likely* range of relative SLR by 2100 to range between +32 cm and +62 cm above the end of the 20th century level for the RCP2.6 scenario, and between +58 cm and +110 cm for the RCP8.5 scenario (Zanchettin et al. 2021).

It is virtually certain that global mean sea level will continue to rise over the 21st century. Relative to 1995-2014, the *likely* global mean sea level rise by 2100 is +0.28 m to 0.55 m under the very low emissions scenario (SSP1-1.9); +0.32 m to +0.62 m under the low emissions scenario (SSP1-2.6); +0.44 m to +0.76 m under the intermediate emissions scenario (SSP2-4.5); and +0.63 m to +1.01 m under the very high emissions scenario (SSP5-8.5), and by 2150 is +0.37 m to 0.86 m under the very low scenario (SSP1-1.9); +0.46 m to +0.99 m under the low scenario (SSP1-2.6); +0.66 m to +1.33 m under the intermediate scenario (SSP2-4.5), and +0.98 to +1.88 m under the very high scenario (SSP5-8.5) *(medium confidence)* (Oppenheimer et al. 2019; IPCC 2023). Accounting for low-likelihood, high-impact outcomes of climate change on sea level rise leads to high-end estimates up to +2.5 m by 2100 and +7m by 2150, depending on the triggering of acceleration processes such as Antarctic marine-based ice-shelves disaggregation (Arias et al. 2021). Model projections suggest that stabilising temperature does not stabilise the sea level but, rather, the rate of sea level rise (Oppenheimer et al. 2019).

2.2.8 Natural and anthropic land subsidence across the Mediterranean coast

Subsidence is a common cause of amplified relative sea-level rise, flooding, and erosion in coastal environments. In the past it has increased and may significantly continue to increase the impacts of sea-level rise in the coming decades (Nicholls et al. 2021; Spada and Melini 2022). In the Mediterranean, coastal subsidence is influenced by crustal movements driven by glacial isostatic adjustment (GIA) and tectonic activity as well as by the compaction of Holocene sediments, notably in the coastal plains and in large deltas (Rovere et al. 2016). Negative land-level changes are driven by tectonic subsidence and natural sediment compaction, often accelerated by anthropic withdrawal of underground fluids (water, oil and gas, as well as drainage of organic soils) (Tosi et al. 2013; Calabrese et al. 2021). In some cases, vertical land movements are driven by localised anthropic activity. The long-term knowledge of vertical land movements is limited to some sites where geological or geodetical surveys have been carried out.

Figure 2.3 shows the vertical land motions detected across Europe during the 2018–2022 period, using Interferometric Synthetic Aperture Radar (InSAR) data from the Sentinel satellites, provided by the Copernicus European Ground Motion Service (EGMS). The coast most affected by land subsidence is on the Italian side of the northern Adriatic from Grado to Rimini, reaching the maximum rate of –8 mm yr^{-1} on the delta of the Po River. In the northern Adriatic, observed and predicted changes can lead to severe coastal submersions and increased saltwater inland in the near future (Kaniewski et al. 2021). The InSAR data may be compared with literature. In the historical centre of Venice, the average value in the literature is –1 mm yr^{-1} (Zanchettin et al. 2021), about 50% of InSAR, while in the lagoon, major subsidence rates have affected the northern sector (–3 mm yr^{-1} to –4 mm yr^{-1}) (Tosi et al. 2018). The Arno and Po deltas have been evaluated at –10 mm yr^{-1} and –7 mm yr^{-1}, respectively (Besset et al. 2017).

In southern Italy, in the Volturno plain, InSAR satellite data defined average subsidence rates at –3 mm yr^{-1} (Di Paola et al. 2021) while in the coastal plain of Catania, rates ranging from –6 to –12 mm yr^{-1} have been calculated (Anzidei et al. 2021).

In the Ebro (Spain) and Rhône (France) deltas, vertical rates of –2 mm yr^{-1} and –1.4 mm yr^{-1} have been evaluated respectively (Besset et al. 2017).

InSAR data show that there are other sites with high subsidence rates, especially islands (e.g. Ischia and Aeolian Islands, Italy; Symi, Greece) and very localised portions of the coast. Positive uplifts are visible in Greece and the Aegean Sea (Samos, Cyclades Island) but are irregularly distributed over space and over time, even with alternating positive and negative vertical motions, conditioned by the complex tectonic and anthropogenic interactions of the area. In Crete, the western side is uprising, and the eastern sinking (Mourtzas et al. 2015). Major subsidence rates have been observed near Thessaloniki and next to the coastline, reaching rates of –35 mm yr^{-1}, related to the intensive mining and overexploitation of aquifers and reach dangerous values near the sites of such anthropic activity (Svigkas et al. 2016; Loupasakis 2020). Sometimes, ruptures of the crust and rebound may cause opposite local effects, that is land uplift (Loupasakis 2020).

In the southern portion of the Mediterranean Basin, subsidence rates up to –10 mm yr^{-1} have affected

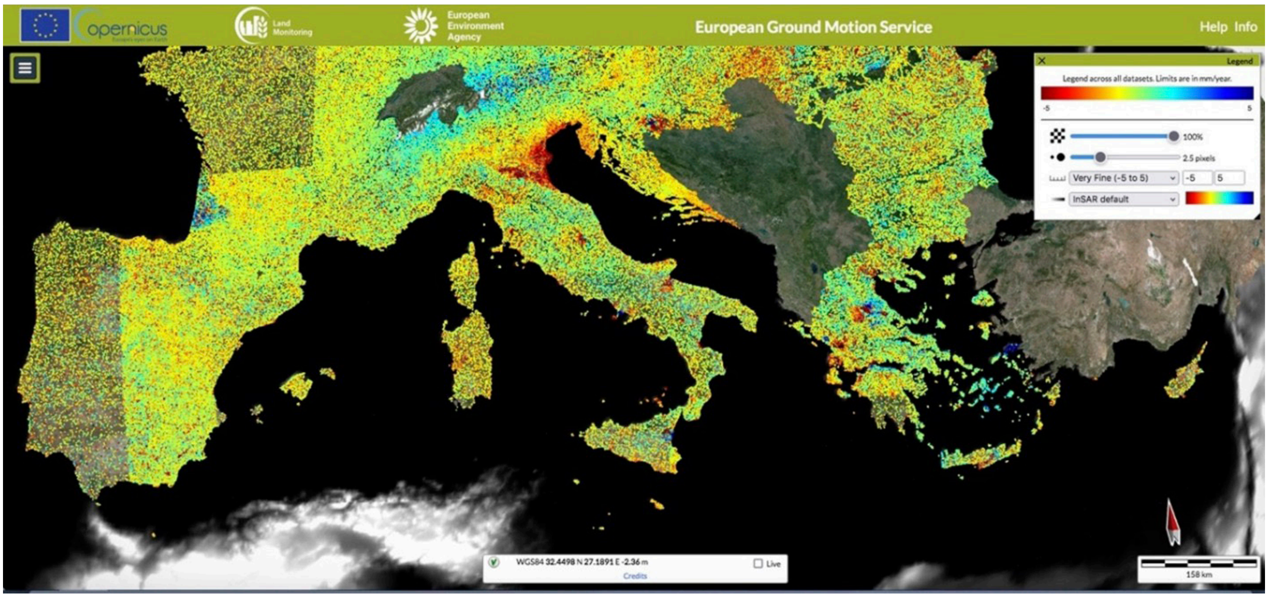


Figure 2.3 | Vertical ground motions over the European coasts of the Mediterranean. InSAR Satellite, Copernicus, European Ground Motion Service data. Period: 2018–2022. https://egms.land.copernicus.eu/

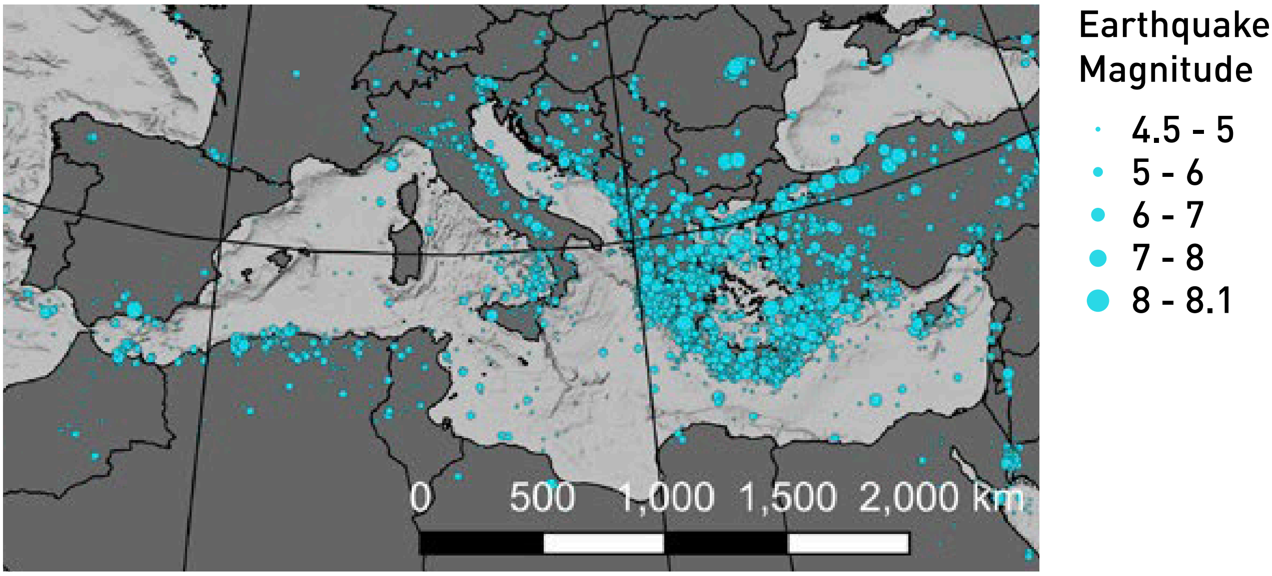


Figure 2.4 | Earthquakes with epicentres M_w>4.4 affecting Europe and the Mediterranean area. Source: Kopp et al. (2021).

the Nile delta (Egypt), and the Medjerda coastal plain (Tunisia) (Besset et al. 2017; Saleh and Becker 2019). Lower subsidence rates of -3 mm yr^{-1} were observed at the Moulouya river mouth (Morocco) (Besset et al. 2017).

In the Black Sea, data are only available for the Danube delta (Romania) which show long-term subsidence rates of -1.5 mm yr^{-1} (Besset et al. 2017).

2.2.9 Geohazards

A geohazard is a geological condition which is – or has the potential to develop into - a situation leading to damage or uncontrolled risk. The major marine geohazards are earthquakes, volcanoes, tsunamis, submarine mass movements, fluid activity and its manifestations, migrating bedforms, human induced and technological hazards (Kopp et al. 2021). Geohazards may have a direct impact on the coast or may generate tsunamis that reach the coast with destructive effects. This section highlights only a few of the major coastal geohazards. Even though the events reported in this section have occurred in the past there is currently no way to predict when similar events will occur in the future using available technology. Other marine geohazards such as liquefaction, active faults, gas seepages, and migrating bedforms are not shown because no standard mapping of these features exists for the Mediterranean Sea (Kopp et al. 2021).

2.2.9.1 Earthquakes

An earthquake manifests in the sudden movement of the Earth's surface, resulting from an abrupt release of energy by the rupture of faults in the crust and upper mantle of the Earth. Earthquakes are among the most damaging geohazards, frequently causing devastating loss of lives, assets and infrastructure, especially in densely populated areas. Earthquakes are the most commonly cited cause of offshore slope failure, especially in seismically active regions with high mountain ranges close to the coast (e.g. Alboran Sea, Ligurian Sea, Calabria region, eastern Sicily, Aegean Sea) which can experience large earthquakes. A collapse of transport infrastructure can be expected either due to ground shaking, landslides or tsunamis (Kopp et al. 2021). A catalogue of the earthquakes that have affected Italy and the Mediterranean area has been published by Guidoboni et al. (2018, 2019).

The Mediterranean Sea, located at the African–Eurasian plate boundary, is subject to strong earthquakes because of its active geology (mainly in Algeria, Italy, Greece, and Türkiye), while two of the five largest volcanic eruptions ever recorded on Earth (Campi Flegrei, Italy 40,000 BCE and Santorini 1600 BCE) occurred in the Tyrrhenian and Aegean Sea. The Mediterranean seafloor is characterised by countless mass movement processes, including submarine landslides, debris avalanches and large turbidity flows. Steep continental slopes fed by mountain-supplied rivers are prone to seabed instability and, because of high sedimentation rates and the retrogressive evolution of the canyon heads that often reach the coast, small landslides are ubiquitous (CIESM 2011).

The largest and most destructive subduction zone earthquake with the moment magnitude $M_w>8$ occurred in 365 CE offshore of Crete Island (Shaw et al. 2008). Offshore of Crete, it caused an instantaneous uplift of western Crete by more than +6 m and triggered a catastrophic tsunami that impacted nearly all coastal areas around the eastern Mediterranean Sea.

Coastal Earthquakes with epicentres with a Moment Magnitude of M_w >4.5 are shown in *Figure 2.4.*

2.2.9.2 Volcanoes

Volcanoes may form at, or near, the margins of tectonic plates where magma reaches the surface, or over hotspots, i.e. over deep magma sources located in the Earth's lower mantle. In the sea, volcanoes may be completely submerged or grow large enough to form islands or coastal volcanoes, many of which have been inhabited since prehistoric times to benefit from the fertile soils.

The most hazardous Mediterranean volcanoes are shown in *Figure 2.5.* The central and western Mediterranean include Mount Etna, Vesuvius, Ischia, Campi Flegrei in the Gulf of Naples, Stromboli and Vulcano in the Aeolian Islands, Pantelleria Island and Ferdinandea volcano. These rank amongst the world's most active volcanoes. Mount Etna and Vesuvius have been designated as Decade Volcanoes by the United Nations, worthy of close study in light of their potentially large, destructive eruptions and proximity to densely populated areas. In the Tyrrhenian Sea, the Marsili Seamount is active with eruptions; possible flank collapses would generate tsunamis affecting the whole southern Tyrrhenian Sea (Teresita et al. 2019). In the eastern Mediterranean, the main marine seismogenic zones are the Calabrian, Hellenic and Cyprus arcs and the North Anatolian Fault, all of which are recurrent sources of tsunamis. The Hellenic Arc creates large earthquakes commonly associated with large tsunamis. The major geohazards in the northern Aegean Sea and the Sea of Marmara originate from the activity of the North Anatolian Fault: the major boundary between the Eurasian and Anatolian-Aegean plates.

2.2.9.3 Submarine landslides

Submarine landslides are a broad term for indicating the phenomena of failure of near-seabed sediments under the effect of gravity. This occurs due to the combination of stresses applied to the seabed with the ensuing environmental conditions that might cause sediment weakening (Scarselli 2020). Submarine landslides may have several negative consequences, for example: triggering tsunamis, causing the collapse

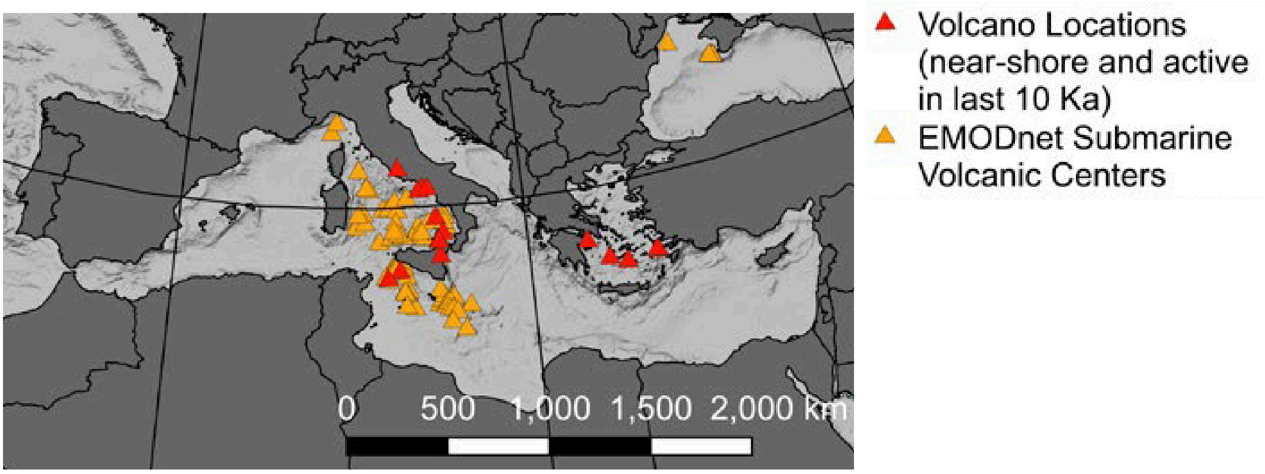


Figure 2.5 | Location of mapped submarine, island and nearshore volcanoes (red when active). Other volcanic sites that were active less recently or lie too far from shorelines to represent a marine hazard are excluded. Source: Kopp et al. (2021).

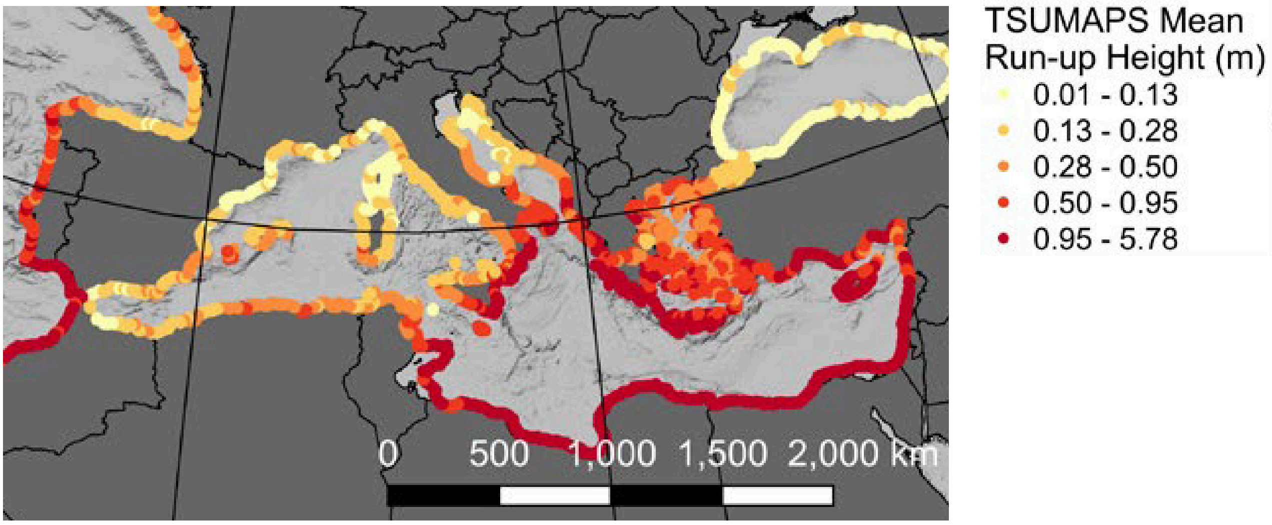


Figure 2.6 | Coastal hazard from seismically induced tsunamis. The mean run-up height (m) was calculated by Basili et al. (2021). Tsunamis induced by landslides are not considered. Source: Kopp et al. (2021).

of coastal areas into the sea; destroying seabed infrastructure; mobilising huge amounts of seafloor material; breaking submarine pipes and cables.

The pattern of landslide-generated tsunamis is more radial than in the case of earthquake sources, and displays different properties, e.g. they are more affected by frequency dispersion, lower tsunami celerity, shorter wavelength and faster wave amplitude attenuation. These factors limit the far-field propagation of tsunamis. However, in places where submarine landslides occur along coastal slopes, the distance to the coastline, and hence the propagation time, is often too short to allow coastal populations to be alerted and evacuated (Rodriguez et al. 2017).

In the Mediterranean Sea, Urgeles and Camerlenghi (2013) reported 696 submarine landslides covering 18% of the seafloor. Their distribution has higher density near the major deltaic wedges, while tectonically active margins are characterised by relatively small failures. In the Mediterranean Sea, small submarine landslides occur every year, while those with volumes larger than 10 km^3 have a return period of 1000 years (Urgeles and Camerlenghi 2013). Except for a number of studies in the Mediterranean (Camerlenghi et al. 2010; Urgeles and Camerlenghi 2013) and in the northern part of the Alboran Basin (Casas et al. 2011; Alonso et al. 2014), most of the submarine landslide geometries and chronologies are yet to be described, and their causal factor are still poorly known (d'Acremont et al. 2022).

2.2.9.4 Tsunamis

A tsunami is a succession of waves of extremely long wavelength, that move the whole column of water from sea floor to the surface, generated by a powerful, underwater disturbance that causes a sudden displacement of a large volume of water from the sea floor (Kopp et al. 2021). Tsunamis may be triggered by earthquakes, volcanic eruptions, submarine landslides, and onshore landslides in which large volumes of debris fall into the water (USGS 2006).

The European GITEC-TWO tsunami catalogue (Tinti et al. 2001) contains 94 reliably assessed earthquake-generated tsunami events during the last 2500 years (Sørensen et al. 2012). Another catalogue including 135 past tsunamis in the Mediterranean has been compiled by Marriner et al. (2017). A map of coastal hazards from seismically induced tsunamis is shown in *Figure 2.6*. The mean run-up height (m) has been calculated using the Probabilistic TSUnami Hazard MAPS for European Coastlines[29] (Basili et al. 2021).

---

[29] https://tsumaps-neam.eu/

In the historical and recent period, several tsunamis have been generated by earthquakes. The most famous tsunamis occurred in 365 CE and 1303 CE in the Hellenic Arc, and the third in 1908, in the Messina Strait (Sicily, Italy). Messina was also previously hit in 1783. The vulnerability of Lampedusa Island and the Messina Strait has been recently simulated with 3D flooding maps (Distefano et al. 2022). Other devastating tsunamis occurred in 373 BCE and 1748 in the Gulf of Corinth (Greece). The most recent destructive tsunamis occurred in the Aegean Sea in 1956 with runup heights reaching +25 m (Papazachos et al. 1985) and northern Algeria in 2003 with runup heights up to +2 m in the Balearic Islands (Alasset et al. 2006). All the above tsunamis were generated by a strong earthquake (Soloviev et al. 2000; Papadopoulos and Fokaefs 2005).

Other tsunamis were generated by volcanic eruptions, such as the eruption of the Thera Volcano (Santorini Island) in the southern Aegean Sea around 1600–1650 BCE, followed by a remarkably strong tsunami (Friedrich et al. 2006). This event has been cited as contributing to the destruction of the Minoan civilization (Soloviev 2000).

2.3 Biological drivers

2.3.1 Non-indigenous species

Species that establish viable populations outside their native ranges can become powerful biological agents of change, causing significant negative effects on human livelihoods and biodiversity (Simberloff et al. 2013; Bacher et al. 2018; IPBES 2019; Shackleton et al. 2019). This problem is set to increase, as the prevalence of these organisms continues to rise worldwide (Seebens et al. 2017). Non-indigenous species are not the only examples of biological drivers. There are other organisms that, despite not having been introduced by humans into a new environment, can colonise areas beyond their natural distribution ranges due to human-induced factors, becoming invasive and causing ecological and economic disruptions.

According to the International Union for Conservation of Nature , non-indigenous species — often called alien, exotic, introduced, non-native or non-indigenous — are plants and animals that have been intentionally or unintentionally introduced, established populations and spread into the wild in the new host region. Moreover, when these species become invasive, they negatively impact native biodiversity, ecosystem services and human well-being.

Non-indigenous species are one of the major agents of coastal biodiversity change, and mostly climate drivers interact to support their spread and colonisation success *(high confidence)* (Iacarella et al. 2020; MedECC 2020; Cooley et al. 2022). They have the potential to displace native species, destroy native genotypes, alter habitats and community structures, alter food web network structure and ecosystem processes, prevent the delivery of ecosystem services and can act as vectors of pathogens and parasites (Grosholz 2002; Perrings et al. 2002; Wallentinus and Nyberg 2007; Molnar et al. 2008; Vilà et al. 2010). As seen in the Mediterranean, non-indigenous species outcompete indigenous species, causing regional biodiversity shifts and altering ecosystem functions and services *(high confidence)* (e.g. Caiola and Sostoa 2005; Mannino et al. 2017; Bianchi et al. 2019; Hall-Spencer and Harvey 2019; Verdura et al. 2019; Cherif et al. 2020; García-Gómez et al. 2020; Dimitriadis et al. 2021).

The Suez Canal has provided the most important entrance for non-native species in the Mediterranean. Through this man-made passage, hundreds of Red Sea species have reached the Mediterranean since it opened in 1869 (Galil et al. 2017; Zenetos et al. 2017). At present, other pathways such as shipping vectors and the aquarium trade are responsible for a considerably higher number of non-indigenous species introduced (Zenetos and Galanidi 2020).

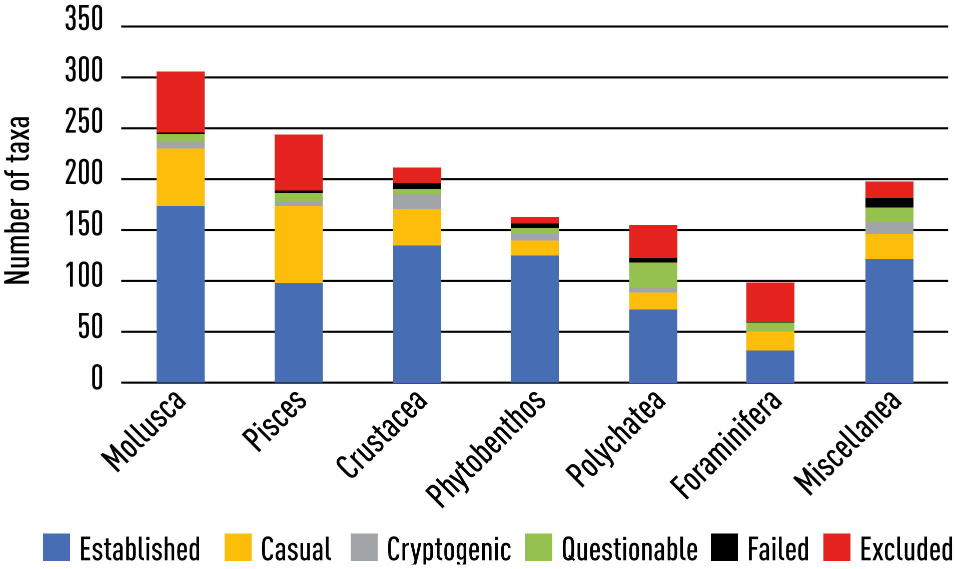


Figure 2.7 | Status of non-indigenous species in the Mediterranean Sea according to their taxa and introduction stages. Source: Zenetos et al. (2022).

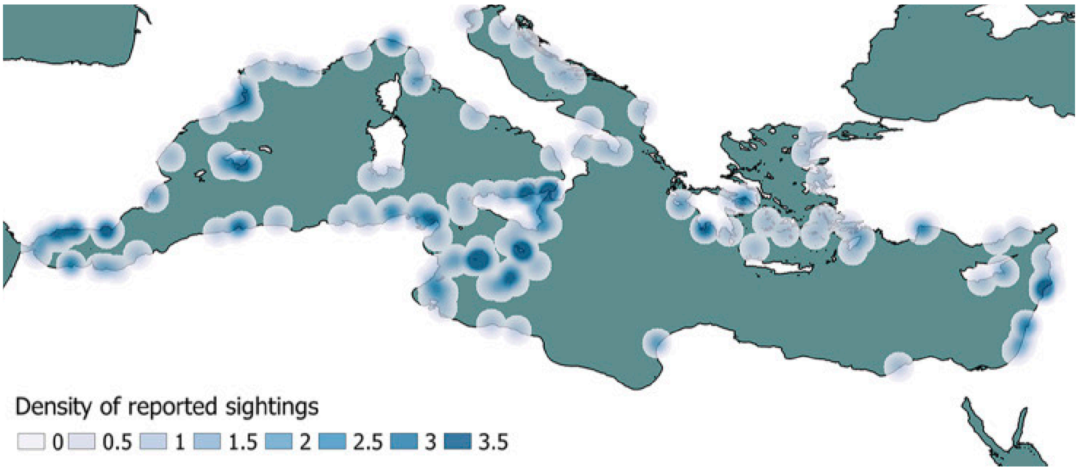


Figure 2.8 | Heat map showing the cumulative density of reported sightings of fish of Atlantic origin (radius = 70 km). These fishes are believed to have entered the Mediterranean through the Strait of Gibraltar without direct human assistance. Source: Azzurro et al. (2022b).

Several of these organisms have established large, permanent populations in the eastern Mediterranean and are spreading westwards. The main introduction pathways of non-indigenous species in other Mediterranean coastal and transitional ecosystems such as estuaries or coastal lagoons are accidental introductions from aquaculture facilities (e.g. Caiola and Sostoa 2005), aquarium species trade (e.g. Hamza et al. 2022) and boats' ballast waters (e.g. Gollasch et al. 2019) and biofouling on recreational vessels (Ulman et al. 2019).

With over a thousand non-indigenous species, the eastern Mediterranean, which is a major invasion hotspot (virtually certain) (Edelist et al. 2013), is the most heavily invaded marine region in the world (Zenetos and Galanidi 2020; Golani et al. 2021; Azzurro et al. 2022a) and suffers from continuous invasion of exotic species (Azzurro, Smeraldo, Minelli, et al. 2022). Non-indigenous species in the Mediterranean coasts began to occupy depths below 200 m (Dalyan et al. 2012). However, it should be noted that most of the reported non-indigenous species in the Mediterranean Sea are coastal species *(Figure 2.7)*, probably because the depth of the Suez Canal (24 m) creates a geographic isolation that limits the passage of deep-sea species. Moreover, shallow coastal ecosystems are more accessible and have been more studied and monitored than the open sea *(Figure 2.8)*. Wetlands, saltmarshes, seagrass beds and sandy beaches are some of the Mediterranean coastal ecosystems with the highest potential of services delivery that interact via non-indigenous species. Moreover, these and other Mediterranean ecosystems are very rich in species and endemism (Coll et al. 2010; Lejeusne et al. 2010).

2.3.2 Changes in the limits of species distribution

Native species will be affected by ocean warming. Some species are changing their life-history traits and patterns which can lead to a loss of competitive abilities to cope with the effects of biological drivers, especially those caused by biological invasions (Cooley et al. 2022; Chatzimentor et al. 2023). As the Mediterranean warms, conditions at the edge of the species' distribution will become warmer. If temperatures reach higher values than the maximum thermal tolerance of the species, local native populations can undergo a gradual decline in performance and a decreasing population size, *very likely* resulting in a range contraction. On the other hand, thermophilic species will show faster dispersal rates and population size increase *(high confidence)* (Azzurro 2008). Assessed future scenarios of marine ecosystem conditions in the eastern Mediterranean showed significant increases of non-indigenous species of the benthic and pelagic macrofauna while native species and vulnerable species decreased *(very high confidence)* (Corrales et al. 2018).

The construction of the Aswan Dam in 1969 caused a drastic reduction of the Nile outflow and, therefore, the freshwater barrier between the Red Sea and the Mediterranean disappeared, increasing the entry of non-indigenous species. The increase in temperature experienced in the last decades also reduces the water inflow to the eastern Mediterranean and increases salinity. The increase in both sea surface temperature and salinity (Theocharis et al. 1999) indicates that the physico-chemical conditions of the eastern Mediterranean have changed in favour of thermophilic species. The waters coming from the Red Sea into the Mediterranean are rich in pelagic eggs and larvae. The survival rates of these eggs and larvae, which have lower ecological tolerance (Downie et al. 2020) than adults, increase due to the similarity of the Red Sea and eastern Mediterranean environments. It is *extremely likely* that the situation will be effective in the population formation process of non-indigenous species in the Mediterranean. Moreover, hydrographic changes triggered by high seawater temperature have increasingly been caused by the expansion of thermophilic biota into the central and western basins of the Mediterranean *(very high confidence)* (Occhipinti-Ambrogi and Galil 2010).

In some cases, non-indigenous species act invasively, and they are listed together with "true" exotic species (Golani et al. 2021). Regardless of where these species came from, understanding the spatial and temporal dynamics of their "invasion" would be helpful to assess the transformation of the Mediterranean biota, which some authors have referred to as 'tropicalisation' or 'Mediterranisation' (Quignard and Tomasini 2000; Bianchi and Morri 2003).

The Mediterranean is warming faster than other seas (Vargas-Yáñez et al. 2008; Schroeder et al. 2016), becoming increasingly suitable to be colonised and invaded by organisms of tropical origin. The effect of global warming is therefore contributing to species colonisation through the Strait of Gibraltar, but also to the dispersal of these and truly non-indigenous species within the Mediterranean.

The Strait of Gibraltar provides a natural connection between the Atlantic and the Mediterranean and enables the passage of species between the two water bodies. Since the Late Miocene, Atlantic species form the main framework of the Mediterranean biota. A heat map showing the cumulative density of reported sightings of fish of Atlantic origin, which are thought to have entered the Mediterranean through the Strait of Gibraltar, without direct human assistance, is given in *Figure 2.8.* A clear geographical pattern is visible with the distribution of records strongly skewed toward the west, indicating the continuous entry of new species from the Atlantic and their expansion towards the east.

There is an exponential dynamic of Atlantic fish entering the Mediterranean between the 1950–2021 period (Azzurro, Smeraldo, Minelli, et al. 2022). Moreover, the expansion of these neo-native species increased exponentially by the mid–1990s and 2000, coinciding with the observed shift in the sea surface temperature of the Mediterranean. Due to global warming, the Mediterranean is becoming increasingly apt to be colonised and invaded by organisms of tropical origin that are expanding their distribution ranges *(high confidence)*. Warming will alter the distribution of invasive subtropical species *(high confidence)* (Cooley et al. 2022; IPCC 2022).

2.3.3 Jellyfish blooms

Although jellyfish blooms are natural events in marine ecosystems, their intensity and recurrence in the last decades have increased significantly (Purcell et al. 2007; Molinero et al. 2008) particularly in coastal waters and semi-enclosed basins (Brotz and Pauly 2012; Brotz et al. 2012). These events are usually very conspicuous and reports of human problems with jellyfish have increased worldwide and have captured public attention[30] (e.g. stinging swimmers, interference with fishing, aquaculture and power plant operations) (B. Carpenter 2004).

According to the Jellywatch Program of the Mediterranean science commission (CIESM) there are a total of 23 main species of jellyfish occurring on the coasts of the Mediterranean and Black Seas that can potentially develop bloom events[31]. Of these, there are nine species of major concern either

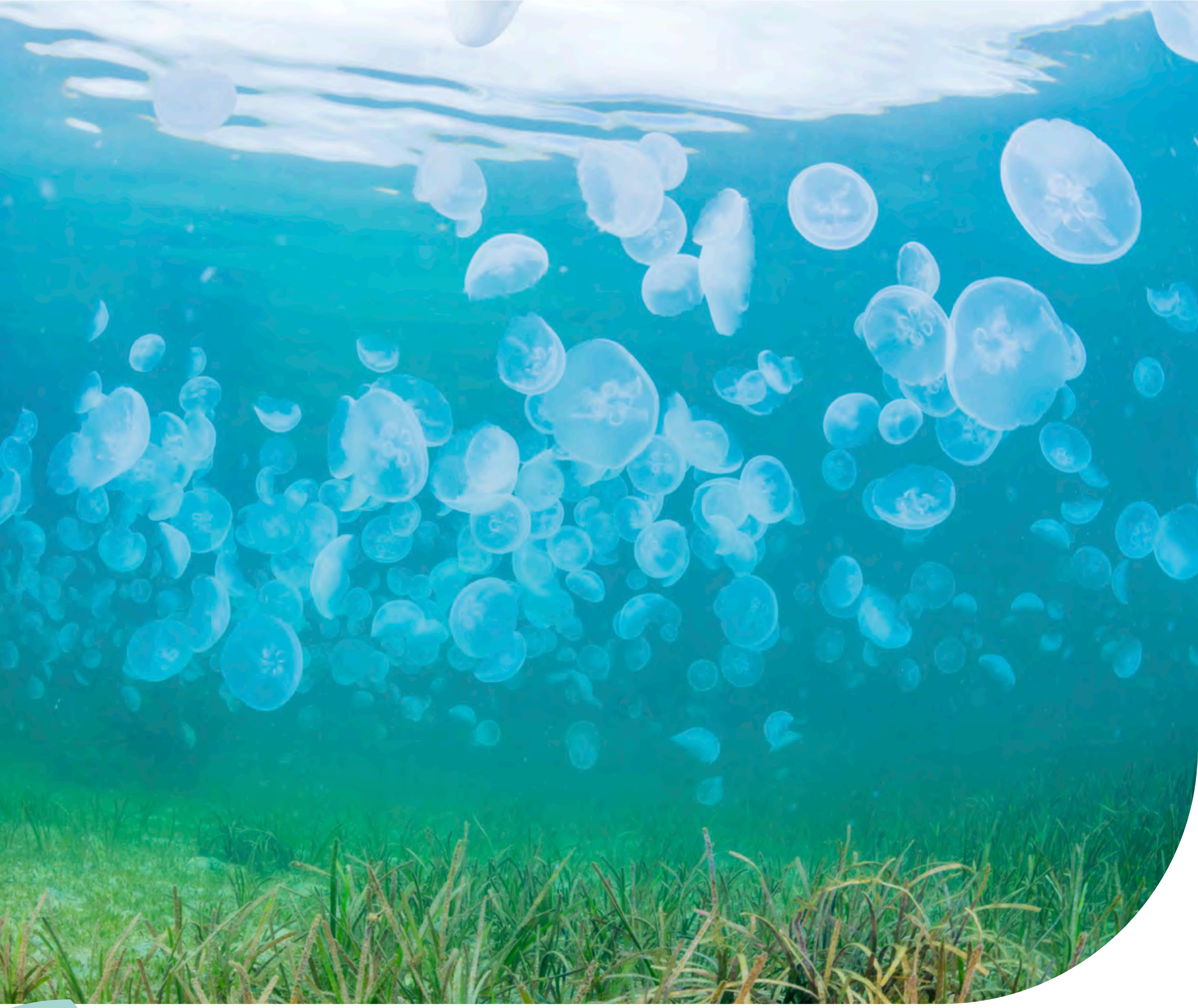
---

[30] https://www.naturalhistorymag.com/naturenet/08995/the-blob

[31] https://ciesm.org/gis/JW/build/JellyBlooms.php

because of the magnitude of the blooms or due to the impacts they may cause (Boero 2013). Five of these species are native to the Mediterranean and the other others are non-indigenous.

Although in some areas, jellyfish have not shown any increase or have even declined (Brotz 2011), there is a general perception of an increase in global jellyfish abundance, with blooms being recorded in different seas across the planet (e.g. Boero et al. 2008; Brotz et al. 2012; Purcell 2012; Condon et al. 2013; Canepa et al. 2014). There is some evidence that jellyfish may benefit from eutrophication and other human induced stressors, such as global warming *(medium confidence)* (Purcell et al. 2007). However, many authors suggest that there is not enough evidence to support an increase in jellyfish blooms because the results from studies on this issue are not based on long time-series data on jellyfish populations (Brotz et al. 2012; Canepa et al. 2014). Nevertheless, recent studies show an increase in the frequency of these blooms in the Mediterranean Sea *(medium confidence)* (Báez et al. 2022).



2.4 Pollution drivers

The majority of pollution in the Mediterranean is caused by land, followed by air and shipping pollution (MedECC 2020). Land-based pollution is essentially made up of point-source pollution such as domestic and industrial effluents and diffuse pollution consisting of the drainage of irrigation water, which carries substances used in agriculture such as fertilisers, pesticides and herbicides as well as storm water runoff from urban areas carrying toxic pollutants from hydrocarbon residues. The Mediterranean Sea has some moderately polluted coasts due to coastal squeeze, intense industrialisation, uncontrolled discharges of municipal and industrial wastewater, river inputs and low seawater circulation (Trincardi et al. 2023).

2.4.1 Nutrients

The input of nutrients, mainly nitrogen (N) and phosphorus (P), is one of the major factors that drives phytoplankton communities. The availability of nutrients and their relative proportions determine algal growth and biomass, and it also determines community composition (Moore et al. 2013).

The Mediterranean is an oligotrophic sea widely recognised as phosphorus-limited (Siokou-Frangou et al. 2010; Álvarez et al. 2023). Nutrient concentrations decrease from the west to the east, and mean values in surface waters may be as low as 0.5 μM for nitrate and 0.01 μM for phosphate in the most oligotrophic eastern region, with substantial nutrient imbalances (Pujo-Pay et al. 2011; Lazzari et al. 2016). Despite the general oligotrophic conditions offshore, there are coastal regions where nutrient concentrations can be very high *(Figure 2.9).* In the north, the largest inputs occur in the Gulf of Lion, the Adriatic, and the northern Aegean Sea (Karydis and Kitsiou 2012; Cozzi et al. 2018; Viaroli et al. 2018). In the southern and south-eastern Mediterranean, the Gulf of Gabès and the Nile-Levantine basin are critical nutrient hotspots, with high concentrations of phosphate, nitrate, and ammonia (e.g. Drira et al. 2016; Kateb et al. 2018; Dorgham et al. 2019; Champagne et al. 2021). Nutrient enrichment of coastal waters occurs via rivers and streams, atmospheric deposition, and submarine groundwater discharge (SGD). River inputs are estimated at 1.9–2.6 Tg N yr^{-1} and 0.11–0.12 Tg P yr^{-1} (Malagó et al. 2019; E. Romero et al. 2021), and basin-wide atmospheric inputs account for 1.3 Tg N yr^{-1} and 0.004 Tg P yr^{-1} (Kanakidou et al. 2020), with a predominant role in the south. The contribution of SGD, for years completely overlooked in nutrient budgets, is now recognised as an essential input, particularly for N (Santos et al. 2021). Rodellas et al. (2015) estimated that SGD could contribute up to 2.6 Tg N yr^{-1} and 0.02 Tg P yr^{-1} to the Mediterranean Sea, hence comparable to fluvial and atmospheric inputs.

There is *robust evidence* that the high fluxes of nutrients transported by air, surface waters and groundwaters to Mediterranean coastal seas are related to agricultural practices and urban and industrial uses. Intensive agriculture and livestock farming, which rely on the massive use of synthetic fertilisers, manure and imported feed, are responsible for heavy N and P pollution (Billen et al. 2011; Viaroli et al. 2018; E. Romero et al. 2021; Lassaletta et al. 2021). Urban areas and industrial facilities are also important sources of N and P, especially in the southern Mediterranean, where the population is increasing rapidly, environmental regulations are less restrictive, and wastewater treatment plants have yet to be widely implemented (Powley et al. 2016; Morsy et al. 2020).

High nutrient loads in coastal areas can lead to a large increase in phytoplankton growth and biomass, resulting in eutrophication. Eutrophication can trigger acidification, hypoxia or anoxia, episodes of massive mucilage formation and harmful algal blooms (HABs). Coastal eutrophication is already an issue of medium or important significance in 13 Mediterranean countries (MedECC 2020). Before 1980, HABs were rarely documented in the Mediterranean Sea. Since then, adverse events and several toxic episodes have been reported in different coastal regions, and harmful phytoplankton species have become dominant in many coastal locations on the northern and southern coasts (Tsikoti and Genitsaris 2021; Zingone et al. 2021; Ligorini et al. 2022). HABs and toxic events are expected to increase in magnitude, frequency, and geographical distribution due to global warming and anthropogenic pressures *(high agreement)* (Hallegraeff 2010; Glibert 2017). This is a serious threat, notably in semi-enclosed bays and estuaries, coastal lagoons and deltas with high productivity and that are close to highly populated areas.

Changes in the stoichiometry of nutrient inputs (N/P ratio) are also crucial to consider when addressing the state of coastal waters, as nutrient imbalances can induce changes in planktonic communities and promote HAB proliferation, as can high nutrient loads (Justić et al. 1995; Glibert 2017). The median N/P of Mediterranean river exports during the 2000–2010 period was 44 (E. Romero et al. 2021), well above the Redfield N/P value of 16. Moreover, a steady increase in N/P ratios has been described in many rivers worldwide (Beusen et al. 2016; Ibáñez and Peñuelas 2019), and the Mediterranean is no exception to this global trend. Aerial and SGD inputs could further exacerbate these elevated N/P ratios (Rodellas et al. 2015; Kanakidou et al. 2020).

Nutrient (N, P) flows from rivers to coastal areas have decreased in most parts of the northern Mediterranean for the past decades (Ludwig et al. 2010; E. Romero et al. 2013) and there is *high agreement* that they may further decrease in the coming years following the implementation of European environmental regulations (Grizzetti et al. 2021). However, river nutrient exports have increased in southern and eastern Mediterranean regions, and growing trends are expected in the future if urban development and agricultural intensification continue at the current pace *(high confidence)* (Ludwig et al. 2010; Powley et al. 2018; UNEP/MAP and Plan Bleu 2020). Atmospheric N deposition is projected to increase only slightly (4%), while airborne soluble P fluxes may decrease by 34% compared to current values (Kanakidou et al. 2020). The discharge of N from SGD will increase in the north and the south in the years to come *(medium confidence)* (Powley et al. 2018).

Finally, nutrient pollution in coastal waters may be enhanced through several processes. Projections suggest that climate change, in interaction with other drivers (mainly demographic and socio-economic developments including unsustainable agricultural practices), is *likely* to impact most of the Mediterranean Basin through increased water scarcity *(high confidence).* Water scarcity challenges water quality because lower flows reduce the dilution capacity of streams and aquifers. Warming and increased seawater temperatures can also trigger mucilage outbreaks (Schiaparelli et al. 2007). Nutrient pollution will also suffer from the loss and degradation of ecosystems that act as natural nutrient buffers. Upstream, projections point at changes in freshwater communities and a decrease in biological processes like nutrient uptake, primary production, or decomposition *(medium confidence).* Downstream, alterations to coastal ecosystems (lagoons, deltas, salt marshes, etc.) directly affect the transfers to the sea. Wetlands, for instance, act as traps of nutrients before they reach coastal areas. Half of the wetland area has been lost or degraded since 1970, and this trend is expected to continue *(high confidence)* (Perennou et al. 2020).

2.4.2 Trace metals

Metal trace elements such as cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), nickel (Ni), and zinc (Zn) are naturally occurring in the Earth's crust (Navarro-Pedreño et al. 2008). Some metals, such as Cd, Hg, and Pb, and metalloids, such as arsenic (As), are not essential for living things and are toxic even in minute concentrations. In addition to these trace elements of major concern, Technology-Critical Elements (TCEs) such as platinum (Pt), tellurium (Te), germanium (Ge), lanthanum (La), and gallium (Ga) have been released from emerging technology and introduced into Mediterranean coasts (Abdou et al. 2019; Romero-Freire et al. 2019) There is increased evidence that human activities have increased trace metal concentrations on Mediterranean coasts (Belivermiș et al. 2016; Tovar-Sánchez et al. 2016; Cherif et al. 2020). There is *high confidence* that urban and industrial wastewaters, atmospheric deposition and run-off from metal-contaminated sites constitute the major sources of trace metals in coastal areas (Cherif et al. 2020; Trincardi et al. 2023).

Lead, mercury, and cadmium hotspots were essentially located on the north-central and south-eastern shores of the Mediterranean Basin (Cherif et al. 2020). The main sector contributing to the release of heavy metals in southern Mediterranean countries is the manufacturing of refined petroleum products. For the Balkans and Türkiye, the main contributing sectors are petroleum products refining, and the manufacturing of cement. For the Mediterranean EU countries, the principal sector is energy production responsible for the release of heavy metals (EEA-UNEP/MAP 2021). In the western Mediterranean coastal waters, high Cd, Hg, Ni, and Pb levels were reported in the Alborán Sea, north-western Mediterranean, Tyrrhenian Sea, North Africa, respectively, while the rest of the western Mediterranean displayed moderate metal pollution

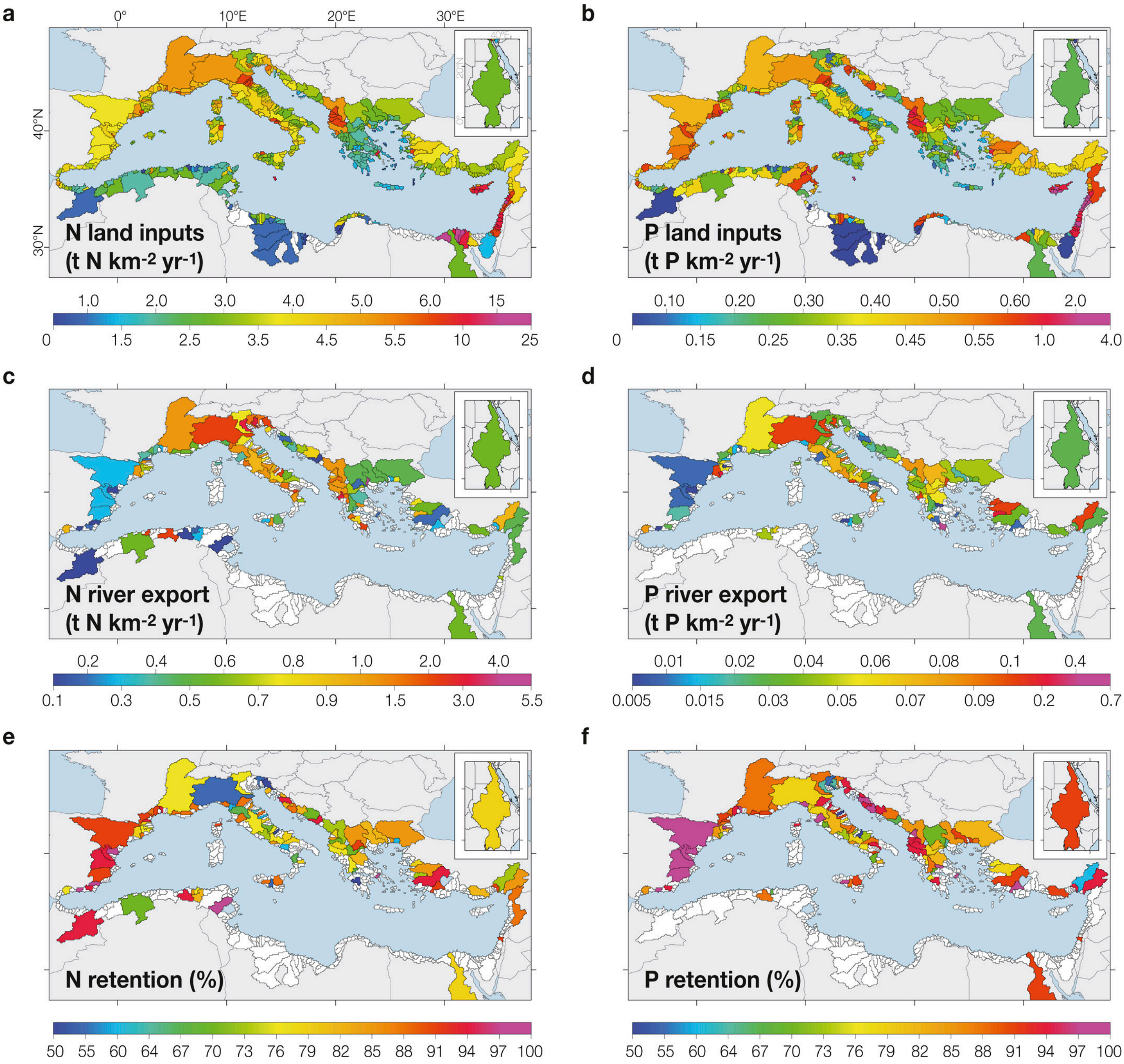


Figure 2.9 | Total land inputs and river exports of N (on the left column) and P (on the right column) into the Mediterranean Sea. a-b: spatial variability of land inputs within the basins (data at 5 arc min resolution); c-d: land inputs averaged per river basin; e-f: river exports averaged per river basin. About 10-25% of all N land inputs and 8-12% of P inputs are directly exported by rivers to coastal seas. Modified from E. Romero et al. (2021).

(Benedicto et al. 2011). On the eastern Mediterranean coasts, the highest concentrations of metals were reached in the pollution hotspots, heavily impacted by human activities. For instance, the highest Cu, Pb, and Zn concentrations were detected in the sediment samples of Alexandria harbour (Egypt) while the highest As, Cd, Cu, Hg, Pb, and Zn concentrations were detected in the sediment samples of Priolo, Gela, Taranto and Crotone (Italy) (Lipizer et al. 2022). Hg concentrations in many Mediterranean top-predatory fish exceed European Union regulatory thresholds. MeHg (methylated mercury) is bio-magnified in marine food webs more efficiently compared to Hg. MeHg concentrations are twice as high in the waters of the western Mediterranean compared to the eastern Mediterranean *(high confidence)*, and higher in marine food in the west compared to the east *(high confidence)* (Cossa et al. 2022).

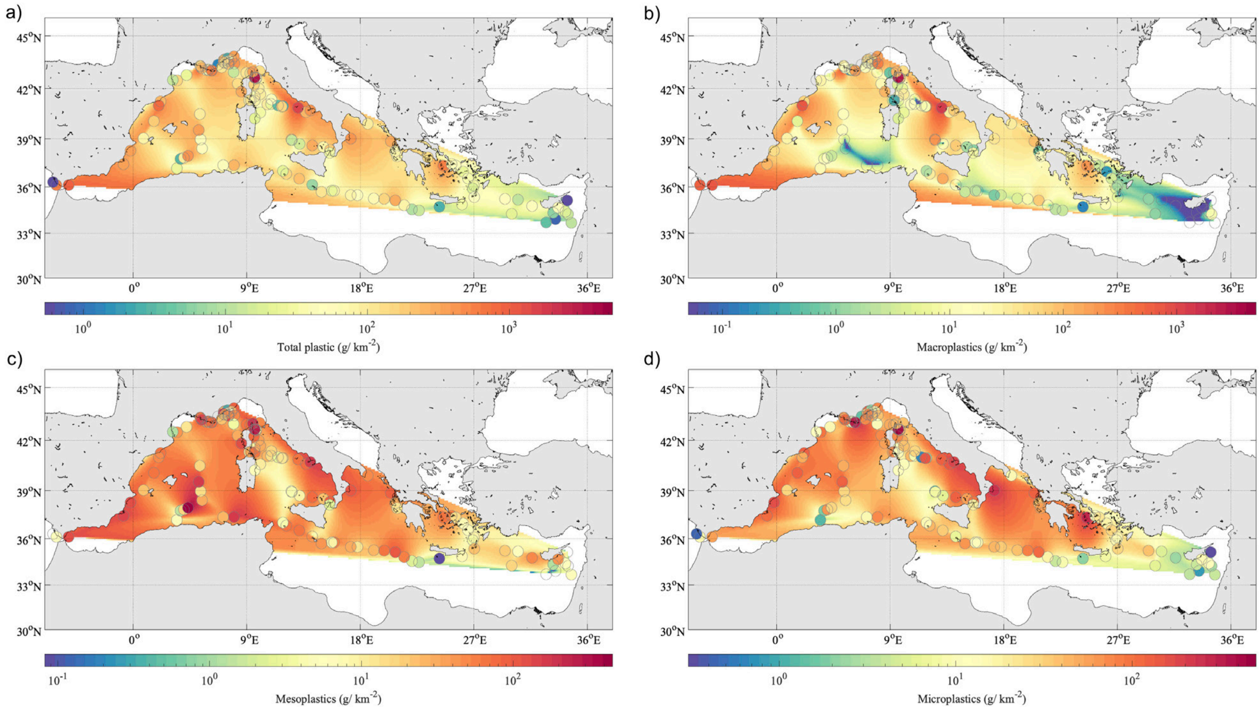


Figure 2.10 | The mass concentrations of floating plastic debris (g km^{-2}) in the Mediterranean Sea. a) total mass concentration, b) macroplastics (>20 mm) c) mesoplastics (between 5 and 20 mm), d) microplastics (<5 mm). Source: Pedrotti et al. (2022).

Levels of Cd, Hg, and Pb in coastal waters show a more or less acceptable environmental status, assessed from bivalves and fish against Background Assessment Concentrations (BAC) and Environmental Assessment Criteria (EAC). In 10% of the stations, Pb levels in mussels were above the maximum concentrations set by the European Commission (EC 2006). For Hg, 53% of the sediment stations assessed are above the Effects Range Low value developed by the US Environmental Protection Agency as sediment quality guidelines, used to protect against potential adverse biological effects on organisms (UNEP/MAP 2017; UNEP/MAP and Plan Bleu 2020).

In summary, for EU countries in the Mediterranean, trends in the release of Cd, Hg and Pb indicate a general decrease (EEA 2021, 2022) *(high confidence).* There is strong evidence that metal concentrations decreased in the northern Mediterranean thanks to regulatory measures *(high confidence)* (Santos-Echeandía et al. 2021; Tavoloni et al. 2021). However, temporal increment trends were reported in some coastal areas, such as Venice (Italy) (Morabito et al. 2018) and the Nile Delta (Egypt) (Mandour et al. 2021).

2.4.3 Persistent organic pollutants (POPs)

Persistent organic pollutants (POPs) are a group of organic compounds that have bioaccumulation potential and toxic properties and persist in the environment. Because of their persistence, these chemicals can be transported through rivers and estuaries and reach coasts and open seas. POPs include pesticides such as dichlorodiphenyltrichloroethane (DDT), industrial chemicals such as polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) (Merhaby et al. 2019; Cherif et al. 2020). There is increased evidence that the Mediterranean Sea is one of the hotspots of POPs in the world (UN 2021).

Industrial discharges, combustion of organic compounds of natural and/or anthropogenic origin and oil spills are the primary sources of POPs (Merhaby et al. 2019; Kılıç et al. 2023). Maritime accidents can lead to chemical pollution (Ülker et al. 2022). Shipping is one of the main sources of oil pollution on Mediterranean coasts. About 90% of tanker spills in the Mediterranean Sea occur near coastlines. In the east, the Levantine Sea coast is the hotspot of oil pollution *(medium confidence)* (Polinov et al. 2021) due to regional political instability and extensive coastal oil facilities.

The Ebro and Rhone rivers that flow into the north-western Mediterranean are the primary vectors for contamination by POPs (Marsili et al. 2018). Accordingly, POP levels in the north-western Mediterranean coasts are higher compared to the eastern and southern coasts (Marsili et al. 2018). Most of the Mediterranean countries had no published data regarding the concentration of polychlorinated biphenyls (PCBs) on their coasts. There is increased evidence that Italy, France, Spain and Egypt were flagged as the countries most polluted Mediterranean with PAHs and PCBs (Merhaby et al. 2019; Trincardi et al. 2023). The highest PAH and PCB levels are around the harbour and industrial areas, as in the case of Lazaret Bay (France), Naples Bay (Italy), and the Gulf of Taranto (Italy) (Di Leo et al. 2014; Merhaby et al. 2019).

Overall, the levels of POPs, specifically polychlorinated dibenzodioxins (PCDD), polychlorinated dibenzofuran (PCDF) and volatile organic compounds (VOCs) have generally declined on the Mediterranean coasts *(high confidence)* (EEA-UNEP/MAP 2021). Levels of most POPs on the coast will *likely* decline with the improvement of wastewater treatment and the banning of certain compounds (Piante and Ody 2015) as in the case of DDT (Combi et al. 2020; Trincardi et al. 2023) and PCBs (Marsili et al. 2018; Combi et al. 2020; Kılıç et al. 2023). Despite the general decreasing trend in POP levels on the Mediterranean coasts, there is a growing trend in maritime transport, port activity and the production of offshore gas and oil in the Mediterranean Sea (Piante and Ody 2015), which release POPs.

2.4.4 Plastics

Disposal of manufactured and processed solid waste in the marine environment, known as marine litter, is one of the major threats to Mediterranean coasts (Boucher and Billard 2020; Cherif et al. 2020; UNEP/MAP and Plan Bleu 2020). Plastics account for up to 82% of observed litter, 95–100% of total floating marine litter and more than 50% of seabed marine litter in the Mediterranean Sea (UNEP/MAP and Plan Bleu 2020; González-Fernández et al. 2021). Floating plastics squeeze along the coasts due to human activities (tourism, fishing activities, industrial and municipal wastewater) and the unique hydrodynamics of the semi-enclosed Mediterranean Basin (Trincardi et al. 2023).

There is increased evidence that the Mediterranean Sea is one of the areas most polluted with plastics across the globe due to its high coastal population density and its connection with populated rivers coasts (Boucher and Billard 2020; Cherif et al. 2020; UN 2021). In the Mediterranean, 67% of all the plastic particles crossing the land-source buffer zones remain on the coasts (Baudena et al. 2022). According to models, predicted plastic fluxes are highest in the following coastal areas of the Mediterranean: Mersin (Türkiye), Tel-Aviv (Israel), Syria, Algiers (Algeria), Barcelona (Spain), Bizerte (Tunisia), Alexandria (Egypt), and the Po delta (Italy). The models also showed that daily plastic debris flux on the coastline (kg km^{-1}) is the highest in Türkiye's Cilicia region (Mersin) followed by Barcelona and Tel-Aviv (Liubartseva et al. 2018; Baudena et al. 2022). Italy (12.6 kT y^{-1}) and Türkiye (12.1 kT y^{-1}) accumulate the most coastline plastic debris each year due to the length of their coastlines and the elevated plastic leakage in coastal waters *(high confidence)* (Liubartseva et al. 2018; González-Fernández et al. 2021; Baudena et al. 2022).

Contrary to the models, floating mega debris (>30 cm) is more significant in the west and the centre of the Mediterranean compared to the east (Lambert et al. 2020). Accordingly, macroplastics (>20 mm), mesoplastics (between 5 and 20 mm), and microplastics (<5 mm) concentrations are higher in the west and the centre compared to the east (Pedrotti et al. 2022). For instance, surface water plastic debris levels are high ($> 5 \times 10^5$ items km^{-2}) in coastal areas from Nice to Toulon (Ligurian Sea), north-eastern Sicily, Messina Channel, and Naples coasts (Tyrrhenian Sea), the Gulf of Taranto (Ionian Sea), and the Saronic Gulf (Aegean Sea), while levels are low ($<1.6 \times 10^4$ items km^{-2}) in Sicily, southern Crete (Ionian Sea), and southern and eastern Cyprus (Levantine Sea) *(Figure 2.10)*.

In summary, the amount of plastic along Mediterranean coasts has remained steady for the past two decades *(medium confidence)* (UN 2021). Annual plastic leakage into the Mediterranean coastal area is as high as 230,000–260,000 tonnes (Cózar et al. 2015; Suaria et al. 2016; Boucher and Billard

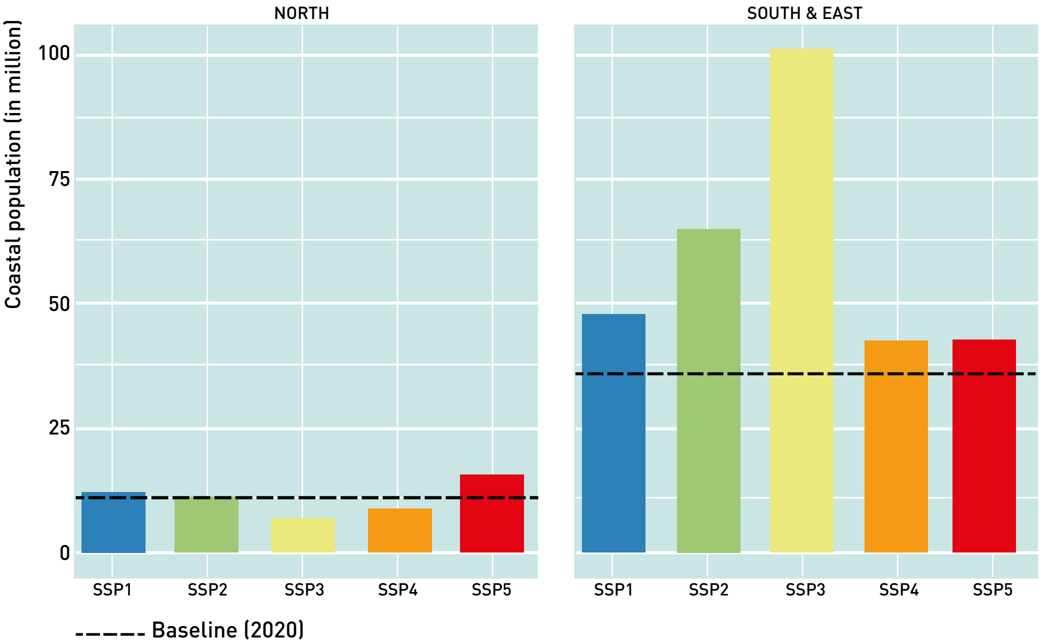


Figure 2.11 | Mediterranean coastal population in each SSP and geographical region in 2100 compared to 2010. (Coastal = LECZ based on MERIT, population in 2010 is based on Global Human Settlement Population Grid; GHS-POP). Please note different scales of the y–axes. Source: Reimann et al. (2021).

2020), and it is *likely* to reach 500,000 tonnes by 2040 if both annual plastic production continues to grow at a rate of 4% and waste management is not radically improved (Boucher and Bilard 2020). In the scenario of 1% annual growth in plastic production, improved waste management and implementing regulations limiting single-use plastic, leakage is *very likely* to decrease by 2040 (Boucher and Bilard 2020).

2.4.5 Emerging pollutants

The term 'emerging pollutants' (EPs) refers to a diverse group of thousands of chemicals and xenobiotics, the biological effects of which are not well-known and whose existence in the environment has only recently been studied and monitored (Cherif et al. 2020; Antunes et al. 2021; Chacón et al. 2022). These chemicals are found in personal care products (cosmetics, etc.), household detergents, flame retardants, plastic additives, pesticides, and pharmaceuticals (painkillers, antibiotics, and antidepressants) that are products of cutting-edge technology (UNEP/MAP and Plan Bleu 2020; Chacón et al. 2022). Runoff and seepage from landfills, pesticides, fertilizers, hospital discharges, industrial and urban wastewater all release EPs into the coastal environment (Li 2014). The low geographical variability of EPs in the Mediterranean Sea suggests that they emanate from diffuse pollution sources such as runoff from agricultural areas (Brumovský et al. 2017). Among the wide variety of EPs, PPCPs (pharmaceutical and personal care products) are those that are the most concentrated in the three river basins in the Mediterranean Sea. In these basins, urban discharges are the primary source of pharmaceuticals like ibuprofen. Pesticide-like chemicals are associated with agricultural activity, while PFOS (perfluorooctane sulfonic acid) are associated with industrial facilities in Mediterranean coasts (Köck-Schulmeyer et al. 2021). On Mediterranean coasts, the levels of pharmaceuticals ranged from 100 to 10,000 or even 100,000 ng L^{-1} in sewage waters, dropping to 1 to 10,000 ng L^{-1} in rivers and not detected to 3000 ng L^{-1} in coastal seawater. Among the 43 drugs, pharmaceuticals highlighted thirteen compounds that are cause for concern in Mediterranean coasts, such as antibiotics and anti-inflammatories (Desbiolles et al. 2018). Anti-inflammatories and antibiotics are the most dominant types of PPCPs in the eastern and southern Mediterranean (Ouda et al. 2021).

EPs, such as pharmaceuticals and personal care products, are expected to increase on the Mediterranean coasts due to socioeconomic changes and emerging industries *(medium confidence).* The northern Mediterranean coasts are polluted with EPs more severely than the south due to the abundance of point sources on the northern coast *(medium confidence).* However, EP levels are elevated in the rivers of some Mediterranean countries, such as Israel, Spain, Tunisia, Türkiye, and Palestine *(low confidence)* (Wilkinson et al. 2022). Active pharmaceutical ingredients are elevated due to the discharge of untreated sewage in Tunisia and Palestine *(low confidence)* (Wilkinson et al. 2022).

2.4.6 Air pollution

Energy consumption, road transport, shipping emissions and the manufacturing and extractive industries are the main sources of air particulate matter in the northern and eastern Mediterranean (Cherif et al. 2020). There is *high confidence* that air quality on Mediterranean coasts is negatively affected by airborne particulate matter ($PM_{2.5}$–PM_{10}; particulate matter diameters of 2.5 and 10 microns or less, respectively) and gases from northern and eastern Europe, desert dust from the Sahara and surrounding arid regions, biomass burning (forest fires), in addition to local pollution sources such as ports, vehicular traffic, industrial and residential heating (Dulac et al. 2022; Perrone et al. 2022).

Air pollution monitoring and related data are scarce in the southern and eastern Mediterranean (except for Greece and Türkiye) compared to the north *(high confidence)*. Having said that the data is scarce in the southern Mediterranean, the highest concentrations of particulate matter and benzo[a]pyrene (a carcinogenic organic pollutant) were reported in central eastern Europe and Italy due primarily to the burning of solid fuels for domestic heating and their use in industry. In 2020, some Italian and Turkish coastal areas showed $PM_{2.5}$ and PM_{10} concentrations higher than EU limit values. PM concentrations in certain coasts of the southern Mediterranean are much higher than the EU and World Health Organization (WHO) limit values *(low confidence)* (Naidja et al. 2018). Emissions from road traffic, resuspension of road dust and natural contributions (i.e. dust from the Saharan Desert) are principal sources of air particles on southern Mediterranean coasts (Naidja et al. 2018).

The eastern Mediterranean and the Middle East are characterised by high background tropospheric ozone concentrations *(high confidence)* (Lelieveld et al. 2002; Georgiou et al. 2022). Ozone levels were lower in 2019–2021 than in previous years, but still high in central Europe and some Mediterranean coastal areas such as the Turkish coasts *(medium confidence).* Concentrations of NO_2 and Benzo[a] pyrene (BaP) are higher on the Greek and Italian coasts, respectively, than the limit value set by the EU *(medium confidence)* (EEA 2021 2022a). Cyprus faces challenges with the exceedance of air quality limits and compliance with European regulatory standards *(medium confidence)* (Georgiou et al. 2022).

15% of global shipping activity and around 18% of global crude oil shipments take place in the Mediterranean Sea (A. Carpenter and Kostianoy 2018). Luxury cruise ships emit up to 18-, 10-, and 4-times higher SO_x than all of the passenger vehicles (including cars) respectively in Spain, Italy, and Greece, the top cruise ship polluted countries in Europe (T&E 2019). However, shipping in many coastal areas of the Mediterranean Sea caused less O_3 and NO_2 release than those of the North and Baltic Seas since shipping lanes are typically further from the coast in the Mediterranean Sea (Fink et al. 2023). Shipping contributions to $PM_{2.5}$ or PM_{10} emissions (between 0.2% and 14%) are greater in the Mediterranean area compared to northern Europe (Contini and Merico 2021). Among the world's harbours (mostly European harbours), Taranto (Italy) has the highest PM_{10} concentrations (Sorte et al. 2020).

In summary, emissions of all key air pollutants in Mediterranean EU countries have been declining since 2005 *(high confidence).* Emissions of sulphur dioxide and nitrogen oxides have fallen by 76% and 36%, respectively, since 2005. $PM_{2.5}$–PM_{10} emissions fell by 29% and 27% respectively, since 2005 across the northern and eastern Mediterranean (EEA 2021 2022a). However, the release and levels of air pollutants will increase *more likely than* not on some Mediterranean coasts due to the upward trend in wildfires (Ruffault et al. 2020), port activity, maritime transport, offshore gas and oil production (Piante and Ody 2015; Doussin 2023).

2.5 Social and economic drivers

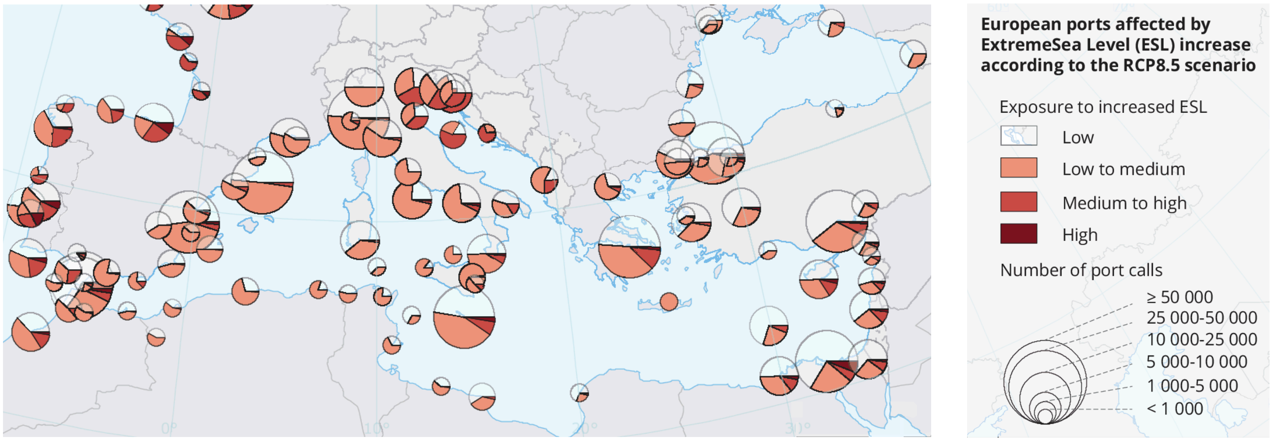
2.5.1 Current and future population and urban development trends across the coastal region

Mediterranean countries are currently home to more than 540 million people, with a high concentration of urban settlements and infrastructure near the coast (Ali et al. 2022). Mediterranean communities have adapted their lifestyles to the historically stable coastline due to non-dynamic water levels, unique to the Mediterranean due to its low-energy wave conditions (Vafeidis et al. 2020). Consequently, about one-third of the Mediterranean population currently lives in close proximity to the coast (UNEP/MAP and Plan Bleu 2020). The Mediterranean Low Elevation Coastal Zone (LECZ, areas below 10 m) hosted more than 41.8 million people (share 8.9%) in 2010 (Reimann et al. 2018). Southern and eastern Mediterranean countries face a higher risk of climate-related coastal exposure, primarily due to higher urban population density, which is three orders of magnitude higher compared to the north (Reimann et al. 2021).

The future population in the Mediterranean coastal region is projected to increase under all socio-economic scenarios, leading to significant exposure to sea-level rise and coastal hazards in the north, south, and east (see *Figure 2.11*). In the northern Mediterranean, Shared Socioeconomic Pathway (SSP) 5 leads to the highest coastal population growth (15.2 million), whereas a reduction to 6.5 million is anticipated under SSP3 by the end of the century. In contrast, the southern and eastern Mediterranean are expected to see the greatest population increase under SSP3 (over 100 million), with the lowest coastal population increase under SSP5 (42.7 million) (see *Figure 2.11*) (Reimann et al. 2021).

At the country level, Egypt, Libya, Morocco and Tunisia are currently most exposed to sea-level rise due to their extensive coastal floodplains and large coastal populations *(medium confidence)* (Adams et al. 2014; Ali et al. 2022). According to Neumann et al. (2015), Egypt is the country with the largest population in the LECZ along the Mediterranean coast (26 million; constituting 38% of its total population). In 2000, the Nile Delta's population density was 1075 people km^{-2}, comparable to the population density of Japan or Bangladesh in the LECZ. This population density is projected to increase to 1902 people km^{-2} by 2030 and 2681 people km^{-2} by 2060 (Neumann et al. 2015). In contrast, the lowest total LECZ population is observed in EU candidate countries, namely Bosnia and Herzegovina, Montenegro, Albania and Türkiye (Reimann et al. 2018).

Additionally, urban expansion and the associated concentration of wealth production are increasing



Note: the map illustrates the secondary effects of the disruption of European port operations as a result of a projected increase of ESL until 2100. It is based on information on connections of container ports. The size of the pies represent the total number of connections or port calls and the coloured pieces of the pies represent the part of the total connections to ports exposed to different levels of ESL increased.

Figure 2.12 | Container ports affected by the projected extreme sea level increase according to the RCP8.5 scenario until 2100. Source: Christodoulou et al. (2019).

more rapidly in low-lying coastal regions than inland worldwide (Seto et al. 2011). Mediterranean countries, with their large and increasing urban population (dos Santos et al. 2020), are experiencing rapid coastal urbanisation. This trend increases exposure of human settlements and infrastructure to sea-level rise and its associated hazards (UNEP/MAP and Plan Bleu 2020). Two-third of the Mediterranean population already lives in urban areas, which is higher than the global average (dos Santos et al. 2020). The UN Human Settlements Program projects that by 2050, the urban population in the northern Mediterranean will grow from 140 million in 2005 to about 170 million, and in the south and east, from 151 million in 2005 to over 300 million (UNEP/MAP 2016). Wolff et al. (2020) project increased urban expansion in the coastal floodplain across all regions (including 10 northern Mediterranean countries and Türkiye) by 2100, leading to a substantial increase in coastal exposure. For example, under the SSP5 scenario, urban areas are expected to increases by 67% (2075 km^2) in Italy, 104% (2331 km^2) in France (considering only the Mediterranean coast), and 86% (691 km^2) in Greece within the extended LECZ (E-LECZ, referring to the area below 20 meter elevation that is hydrologically connected to the sea) between 2012 and 2100. Furthermore, tourism drives coastal urban development in the Mediterranean, with over 360 million international tourist arrivals annually, mainly concentrated in coastal zones, which represents nearly one-third of global tourism (UNWTO 2019).

In summary, the Mediterranean coastal region is characterised by rapid and spatially diverse socioeconomic development, mainly influenced by demographic trends and human settlement patterns *(high confidence)* (Vafeidis et al. 2020; Reimann et al. 2021).

2.5.2 The economic use of the coast

2.5.2.1 Seaports, tourism and cruising

Global environmental change exacerbates existing challenges for the population living around the Mediterranean Sea, through climate change, land use changes, increasing urbanisation and tourism and increased energy demand. Tourism will *likely* be affected by climate change through reduced thermal comfort, degradation of natural resources, including freshwater availability, and coastal erosion due to sea level rise and urban development. The net economic effect on tourism will depend on the country and the season. In the Mediterranean, tourist activity is at its highest in summer, coinciding with peak demands from irrigated agriculture which may create tensions regarding water availability *likely* to be exacerbated in the future due to climate change *(high confidence)* (Toth et al. 2018). Northern Mediterranean regions could experience climate-induced tourism revenue decreases of up to –0.45% of gross domestic product per year by 2100 *(medium confidence)* (dos Santos et al. 2020).

The Mediterranean coastal regions are characterised by high socio-cultural wealth resulting from the enormous cultural and socioeconomic diversity around the basin, which is an important cultural, economic and/or heritage asset for the economy (e.g. tourism) and society (dos Santos et al. 2020) (dos Santos et al. 2020). There is a development gap between the northern, southern, and eastern countries in terms of economic growth, income, population growth and education (UNEP/MAP 2016). War and social unrest are examples of pressing problems in several eastern and southern Mediterranean countries that may exacerbate this development gap and therefore have the potential to further reduce adaptive capacity to coastal hazards (Vafeidis et al. 2020). Another example is the European debt crisis, which has weakened the economic sectors and the labour market in northern Mediterranean countries. In addition, other societal challenges such as corruption, demographic change, poverty, social imbalances and/or inequalities are related to economic growth and have a strong influence on the overall adaptive capacity of the Mediterranean region (dos Santos et al. 2020). In summary, the Mediterranean coastal region is characterised by rapid and spatially diverse socioeconomic development, mainly related to demographic trends and human settlement patterns *(high confidence)* (Vafeidis et al. 2020).

The projected climate change will have a number of consequences affecting seaports. Sea level rise (SLR) will cause diffuse shoreline retreat that will depend on the local morphology and will be worsened by local land subsidence. Seaports will be at risk of flooding, therefore reducing their activity *(high confidence)* (see *Figure 2.12*). In port facilities, SLR will put all the infrastructure located too close to the actual sea level at risk of regular and permanent inundation. Changing the water

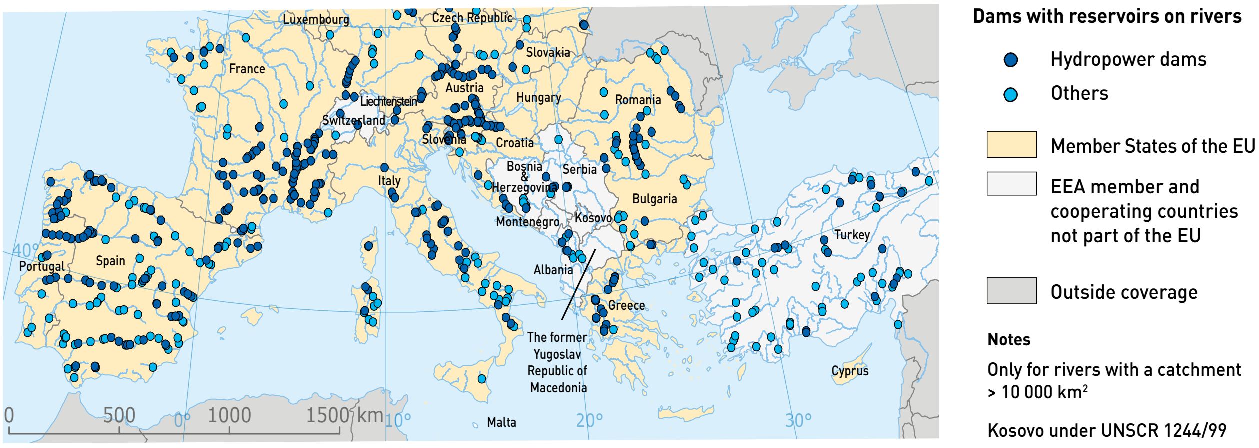


Figure 2.13 | Map of dams in Europe only for rivers with catchment areas greater than 10,000 km². Source: EEA (2016). https://www.eea.europa.eu/en/analysis/maps-and-charts/dams-with-reservoirs-on-rivers

shelf, waves will change the propagation pattern and the way they penetrate into ports. Port infrastructure and/or cargo will be exposed to higher risk of damage. Sand and mud will *likely* increase sedimentation in ports and navigation channels, requiring frequent dredging. Ports will face increased construction and maintenance costs *(high confidence)* (Christodoulou and Demirel 2018; Christodoulou et al. 2019; EMSA 2021). This situation will affect all ports, either for shipping containers or tourism *(high confidence).*

Coastal tourism covers maritime tourism and includes accommodation, transport and other expenditures. The Mediterranean is the world's leading tourism destination in terms of both international and domestic tourism for numerous advantages over other cruising areas, due to its variety of cultural and nature-based-tourism, people, languages, history, gastronomy and the mild climate, even in winter (EC 2022). In addition, the Mediterranean Sea is also a well-known destination for recreational boating (González-Alemán 2020).

Over half of the EU's tourist accommodation establishments are located in coastal areas. Cruise infrastructure remains located on the northern shore: 75% of Mediterranean ports are on the northern coast, while 9% of ports are in Türkiye and Cyprus; and 7% in North Africa; the rest on the eastern Mediterranean side (Plan Bleu 2022).

However, the COVID-19 pandemic and growing geopolitical conflicts are increasing threats for the tourism industry globally, and particularly in the Mediterranean. The tourism sector suffered an 80% decline that will be felt for years to come, with wide uncertainty, and scarce and fragmented knowledge on the current state and path of the sector (EC 2022).

In their efforts to stay competitive, cruise companies introduce continuous innovations, such as new port destinations. Because of this continuous growth, a number of countries think of cruises as key products for tourism development. Some port organisations and local authorities have even decided to build new terminal infrastructure (Kasimati and Asero 2021).

In general, cruise tourism is seen as unsustainable. When big ships arrive at small destinations, this normally has a big impact on the lives of local communities. The biggest problem with cruise tourism is that it generates negative impacts on the environment and may cause overtourism due to the many visitors, who stay only a short amount of time (Asero and Skonieczny 2018). Another drawback is related to the carbon footprint and waste from packaging (e.g. water and beverage packaging) left by passengers who visit ports and other localities on cruise ships (Paiano et al. 2020). However, the cruise industry is slowly responding to the growing demand for sustainability by leading the way in responsible tourism, investing in new ships, and pursuing the goal of net carbon neutral cruising by 2050 (CLIA 2022).

2.5.2.2 Oil and gas extraction and exploration, dams and sediment supply to coastal areas

Oil and gas

In the Mediterranean, the locations with the majority of oil and gas exploration and exploitation activities lie in the eastern Mediterranean Sea, and the eastern coast of Italy in the Adriatic Sea. Drilling wells for offshore production are located in the waters off Egypt, Greece, Italy, Libya, Spain and Tunisia, and along the coasts of Cyprus, Egypt, Israel, Lebanon, and Palestine (A. Carpenter and Kostianoy 2018). Energy industries are intensive consumers of coastal areas. While renewable energies pose specific challenges in terms of logistics, oil and gas industries generate a series of issues in terms of exploration, resource exploitation, and product transportation. Different countries within the Mediterranean Basin manage concessions and royalties in different ways, with most exploitation areas (i.e. coastal regions with at least one offshore platform) located in the eastern side of the Mediterranean Sea. In contrast with other world regions (e.g. Gulf of Mexico, North Sea, Caspian Sea), decommissioning has not been a major issue yet, with main exploitation projects still ongoing and not creating conflicts between local authorities and oil and gas companies (Liaropoulos et al. 2019). Despite this, countries outside the EU do not usually have a specific policy related to decommissioning, arising issues in terms of life-cycle assessments of main exploitation sites and related social and environmental impact.

Another peculiarity of the Mediterranean Basin is connected to the sea conditions that allow companies to enjoy lower costs (and less operational challenges) than in other markets, making many Mediterranean exploitation areas quite competitive with respect to other offshore fields.

Sediments supply and erosion of coastal areas

Throughout the world, coastal areas are constantly threatened by a complex balance between sedimentation and erosion. This problem is the result of multiple factors, which can be divided into three large groups: (1) factors related to climate, e.g. sea level rise, storm, coastal waves, marine currents; (2) factors related to the morphology and quality of the sediment that makes up the beach, as well as to the shoreline morphology (i.e. shoreline orientation), (3) factors generated by the anthropogenic structures and activities that exist in the area (Pagán et al. 2018; López-Olmedilla et al. 2022; Toledo et al. 2022).

In Europe, it is estimated that around 20,000 km of coastline, accounting for 20% of its entire length, have coastal erosion problems (EC 2004). These areas are particularly vulnerable to both human activities and the effects of global warming *(very high confidence).*

Considering sediments and dams, it is worth noticing that the Mediterranean drainage basin incorporates more than 160 rivers, most of which are small and distributed across the European side of the Mediterranean. Poulos and Collins (2002) highlighted how 'suspended sediment contributes some two-thirds of the load, with the remaining third supplied by the combined dissolved and bed-load components'. It has been highlighted that about 46% of the total length of the Mediterranean coastline has been formed by sediment deposition and many Mediterranean deltas have progressed in recent times *(high confidence)* (Poulos and Collins 2002; Anthony 2014, 2019).

Dams within the Mediterranean region have affected river sediments. Most of them are far from the sea but directly influence watersheds. These investments have led to a reduction in the sediment supply to approximately –50% of the potential (natural) sediment supply, directly impacting coastal lands and their composition, especially in the North African area *(high confidence)* (Poulos and Collins 2002).

The sediments supplied by the River Nile have been cut off by dams, sea level rise, marked shelf subsidence, and regional climate changes, which have altered the amounts and components of sediments *(high confidence)* (Frihy and Stanley 2023).

On the European side, the location of dams and their impact on the environment are monitored by the European Environment Agency (EEA 2016) (see *Figure 2.13*) which focuses on understanding their value as water reservoirs and the impact of sediments on coastal development. Within this framework, the European Rivers Network monitors the impact of dams on river ecosystems, highlighting the different effects in the long run with respect to the short run, in terms of sediment balance, need for renovation, and coastal impact of river flows.

Projections of sandy beach erosion due to sea-level rise are affected by large uncertainties. A variance-based global sensitivity analysis indicates that the uncertainty associated with the choice of geophysical datasets can contribute up to 45% (26%) of the variance in coastal land loss projections for Europe by 2050 (2100) *(low confidence)* (Athanasiou et al. 2020).

2.5.2.3 Seawater desalination

The ongoing decrease in precipitation and increase in average annual temperatures include smaller effective meteoric contribution, lower discharge of rivers and higher evapotranspiration. In the coastal areas, this causes a general deterioration of water quality in aquifers due to freshwater salinisation *(high confidence)* (Re and Zuppi 2011). Desalination for drinking water, livestock or agricultural use is gaining importance on islands and in coastal cities with limited water resources. In the Mediterranean, the largest producers of freshwater through desalination are Malta, Algeria, Egypt, Israel, Italy, and Spain. In the Middle East and North Africa, the production of desalinated seawater is projected to be thirteen times higher in 2040 than 2014 *(high confidence)* (FAO 2016; UNEP/MAP and Plan Bleu 2020). Seawater desalination requires a large amount of energy and produces brine potentially impacting the marine ecosystem if not properly managed (Pistocchi, et al. 2020). At the same time, it represents a reliable and constant supply of freshwater in water-scarce regions. Its relatively high cost appears to be increasingly accepted as the costs of conventional water supply (including impacts on ecosystems caused by freshwater abstractions and greenhouse gas emissions) due to pumping, storage and freshwater treatment needs increase. The Mediterranean already has a relatively high share of water supplies provided by desalination, with the European Mediterranean coast alone featuring close to 9 million m^3 day^{-1} in desalination capacity mostly concentrated in Spain and, to a lesser extent, Italy and other countries (EC et al. 2022), accounting for almost 10% of the global capacity. As a hotspot of climate change, projected to face increasingly severe water scarcity, Mediterranean countries *will likely* need to build several new plants in coastal areas throughout the region *(high confidence).* This fact is related to significant greenhouse gas emissions unless sufficient plants able to function with renewable energy sources are designed *(high confidence)* (Ganora et al. 2019; Pistocchi et al. 2020b). Benefits increase when coupling desalination with water reuse *(high confidence)* (Pistocchi et al. 2020b). The Middle East and North Africa (MENA) region is the most water scarce region of the world. High population growth rates, urbanisation and industrialisation, coupled with limited availability of natural potable water resources are leading to serious deficits of freshwater in many parts of the MENA region. Freshwater sources in the MENA region are being continuously over-exploited and increased use of desalinated seawater is unavoidable in order to maintain a reasonable level of water supply *(high confidence).* However, conventional large-scale desalination is cost-prohibitive and energy-intensive, and not viable for poor countries in the MENA region due to increasing costs of fossil fuels. In addition, the environmental impacts of desalination are considered critical on account of emissions from energy consumption and discharge of brine into the sea (*high confidence).*

2.5.2.4 Aquaculture and fisheries

Fishery is an activity involving the harvesting of fish. It may involve capture of wild fish or raising fish through aquaculture (FAO 2023). Aquaculture is based on the cultivation of fish, crustaceans, molluscs, algae and aquatic plants of value in sheltered coastal or offshore waters, as well as in proximity to rivers, ponds, lakes, canals and especially deltas. These activities are currently impacted mostly by overfishing and coastal development, but climate change and acidification may play an important role in the future. Both capture fisheries and aquaculture depend on natural ecosystems. Capture fisheries, in particular, depend on the status of fisheries resources, while aquaculture depends on water quality and the appropriate spatial conditions to carry out these activities. Impacts include fishing itself, but also climate change, pollution, and the appearance and expansion of non-indigenous species. The upward trend in aquaculture production has been driven primarily by increased production in Egypt and Türkiye, followed by Greece, Italy, Spain, France, and Tunisia (UNEP/MAP and Plan Bleu 2020). For fisheries, the most seriously overexploited priority species in the Mediterranean is the European hake, which – due to its presence in most trawl fisheries – shows an average overexploitation rate 5.8 times higher than the target *(high confidence).* For aquaculture, more than 100 species (finfish, shellfish, crustaceans, and algae) are currently cultivated within a wide range of environments and farming systems (UNEP/MAP and Plan Bleu 2020). Mediterranean countries import more fish products than they export as a result of increasing demand for seafood. Despite being major exporters, France, Italy, and Spain are the countries with the highest trade deficits for seafood. There are no quantitative estimates on the impact of climate change on future seafood production in the Mediterranean region, but ocean acidification and warming will *very likely* impact an already-stressed fishing sector *(very high confidence)* (UNEP/MAP and Plan Bleu 2020). By 2040–2059, compared to 1991–2010, more than 20% of fish and invertebrates currently fished in the eastern Mediterranean are projected to become locally extinct under the most pessimistic scenario (RCP8.5) *(very high confidence)* (Jones and Cheung 2015; Cheung et al. 2016). By 2070–2099, forty-five species are expected to qualify for the Red List of the International Union for Conservation of Nature (IUCN) and fourteen are expected to become extinct *(very high confidence)* (Ben Rais Lasram et al. 2010). The maximum catch potential on the southern coast of the Mediterranean Sea is projected to decline by more than 20% by the 2050s with respect to the 1990s under RCP8.5 *(high confidence)* (Cheung et al. 2016).

2.6 Final remarks

Climate change, sea level rise and local land subsidence expose large portions of coasts to risk of permanent submersion, or to the impact of episodic floods driven by adverse meteorological conditions, sometimes worsened by certain anthropic activities *(very high confidence)*. This situation suggests that specific studies should be carried out for planning, or to decide on coastal use and development.

The dramatic and unexpected events of recent years (e.g. the COVID–19 pandemic, the socio-political events that have given rise to new wars, the increased costs of fuels and energy, and recently a devastating earthquake) have negatively influenced many forecasts related to free trade, tourism, development, industry, agriculture, commerce, and several other sectors. This has created a margin of uncertainty that is not easily determinable, not even as regards its duration.

Regarding pollution and biological drivers, comprehensive data sets including all coasts of the Mediterranean are very scarce *(very high confidence)* due to unequal socio-economic structures of the countries across the Mediterranean, political instability and lack of international cooperation. Furthermore, each part of the Mediterranean coast is polluted to varied degrees, and no limit and/or threshold levels of pollutants are approved by all Mediterranean countries *(high confidence).* Large-scale periodic and standardised pollution and biological monitoring campaigns (including all Mediterranean countries) are needed to develop more solid data, reveal the current status and project future scenarios. Capacity building, technology and knowledge transfer among the Mediterranean countries can enhance our understanding of pollution and biological drivers. Setting standard applications for the treatment of municipal and industrial wastewater is *likely* to decrease pollution on Mediterranean coasts.

References

Abdou M., Schäfer J., Hu R., Gil-Díaz T., Garnier C., Brach-Papa C., Chiffoleau J. F., Charmasson S., Giner F., Dutruch L., and Blanc G. (2019). Platinum in sediments and mussels from the northwestern Mediterranean coast: Temporal and spatial aspects. *Chemosphere, 215.* doi: 10.1016/j.chemosphere.2018.10.011

Adams, S., Aich, V., Albrecht, T., Baarsch, F., Boit, A., Canales Trujillo, N., Cartsburg, M., Coumou, D., Eden, A., Fader, M., Hare, B., Hoff, H., Jobbins, G., Jones, L., Kit, O., Krummenauer, L., Langerwisch, F., Le Masson, V., Ludi, E., Marcus, R., … World Bank. (2014). *Turn down the heat: Confronting the new climate normal (Vol. 2 of 5): Main report.* World Bank Group. http://documents.worldbank.org/curated/en/317301468242098870

Adloff F., Somot S., Sevault F., Jordà G., Aznar R., Déqué M., Herrmann M., Marcos M., Dubois C., Padorno E., Alvarez-Fanjul E., and Gomis D. (2015). Mediterranean Sea response to climate change in an ensemble of twenty first century scenarios. *Climate Dynamics, 45*(9–10), 2775–2802. doi: 10.1007/s00382-015-2507-3

Alasset P. J., Hébert H., Maouche S., Calbini V., and Meghraoui M. (2006). The tsunami induced by the 2003 Zemmouri earthquake (MW = 6.9, Algeria): Modelling and results. *Geophysical Journal International, 166*(1), 213–226. doi: 10.1111/J.1365-246x.2006.02912.x

Alexander M. A., Scott J. D., Friedland K. D., Mills K. E., Nye J. A., Pershing A. J., and Thomas A. C. (2018). Projected sea surface temperatures over the 21st century: Changes in the mean, variability and extremes for large marine ecosystem regions of Northern Oceans. *Elementa: Science of the Anthropocene, 6*. doi: 10.1525/elementa.191

Ali E., Cramer W., Carnicer J., Georgopoulou E., Hilmi N. J. M., Le Cozannet G., and Lionello P. (2022). Cross-Chapter Paper 4: Mediterranean Region. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2233–2272. doi: 10.1017/9781009325844.021

Alonso B., Ercilla G., Garcia M., Vázquez J. T., Juan C., Casas D., Estrada F., D´Acremont E., Gorini Ch., El Moumni B., and Farran M. (2014). Quaternary Mass-Transport Deposits on the North-Eastern Alboran Seamounts (SW Mediterranean Sea). In S. Krastel, J.-H. Behrmann, D. Völker, M. Stipp, C. Berndt, R. Urgeles, J. Chaytor, K. Huhn, M. Strasser, & C. B. Harbitz (Eds.), *Submarine Mass Movements and Their Consequences: 6th International Symposium* (pp. 561–570). Springer, Cham. doi: 10.1007/978-3-319-00972-8_50

Álvarez M., Catalá T. S., Civitarese G., Coppola L., Hassoun A. E. R., Ibello V., Lazzari P., Lefevre D., Macías D., Santinelli C., and Ulses C. (2023). Mediterranean Sea general biogeochemistry. In *Oceanography of the Mediterranean Sea* (pp. 387–451). Elsevier. doi: 10.1016/b978-0-12-823692-5.00004-2

Androulidakis Y. S., Kombiadou K. D., Makris C. V, Baltikas V. N., and Krestenitis Y. N. (2015). Storm surges in the Mediterranean Sea: Variability and trends under future climatic conditions. *Dynamics of Atmospheres and Oceans, 71,* 56–82. doi: 10.1016/j.dynatmoce.2015.06.001

Anthony E. J. (2014). The Human influence on the Mediterranean coast over the last 200 years: a brief appraisal from a geomorphological perspective. *Géomorphologie : Relief, Processus, Environnement, 20(3)*, 219–226. doi: 10.4000/geomorphologie.10654

Anthony E. J. (2019). *Beach Erosion* (C. W. Finkl & C. Makowski, Eds.; pp. 234–246). doi: 10.1007/978-3-319-93806-6_33

Antunes E., Vuppaladadiyam A. K., Sarmah A. K., Varsha S. S. V, Pant K. K., Tiwari B., and Pandey A. (2021). Application of biochar for emerging contaminant mitigation. In *Advances in Chemical Pollution, Environmental Management and Protection* (Vol. 7, pp. 65–91). Elsevier. https://linkinghub.elsevier.com/retrieve/pii/S2468928921000034

Anzidei M., Scicchitano G., Scardino G., Bignami C., Tolomei C., Vecchio A., Serpelloni E., De Santis V., Monaco C., Milella M., Piscitelli A., and Mastronuzzi G. (2021). Relative Sea-Level Rise Scenario for 2100 along the Coast of South Eastern Sicily (Italy) by InSAR Data, Satellite Images and High-Resolution Topography. *Remote Sensing, 13*(6), 1108. doi: 10.3390/rs13061108

Arias P. A., Rojas M., Sillmann J., Barimalala R., Berger S., Dentener F. J., Dereczynski C., Eyring V., Fischer E., Gutierrez J. M., Hamdi R., Kossin J., Krakovska S., Ngo-Duc T., Otto F., Sathyendranath S., Seneviratne S. I., von Schuckmann K., and Zaehle S. (2021). Technical Summary. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 33–144. doi: 10.1017/9781009157896.002

Asero V., and Skonieczny S. (2018). Cruise Tourism and Sustainability in the Mediterranean. Destination Venice. In L. Butowski (Ed.), *Mobilities, Tourism and Travel Behavior - Contexts and Boundaries.* InTech. doi: 10.5772/intechopen.71459

Athanasiou, P., van Dongeren, A., Giardino, A., Vousdoukas, M. I., Ranasinghe, R., & Kwadijk, J. (2020). Uncertainties in projections of sandy beach erosion due to sea level rise: an analysis at the European scale. *Scientific Reports, 10*(1), 11895. doi: 10.1038/s41598-020-68576-0

Axaopoulos P., and Sofianos S. (2010). Long Term Variability of Sea Surface Temperature in Mediterranean Sea. *AIP Conference Proceedings, 1203*(1), 899–904. doi: 10.1063/1.3322579

Azzurro E. (2008). The advance of thermophilic fishes in the Mediterranean Sea: overview and methodological questions. In *CIESM workshop monographs.* Vol. 35. CIESM, Monaco. https://www.ciesm.org/online/monographs/35/WM_35_39_45.pdf

Azzurro E., Smeraldo S., and D'Amen M. (2022a). Spatio-temporal dynamics of exotic fish species in the Mediterranean Sea: Over a century of invasion reconstructed. *Global Change Biology, 28*(21), 6268–6279. doi: 10.1111/gcb.16362

Azzurro E., Smeraldo S., Minelli A., and D'Amen M. (2022b). ORMEF: a Mediterranean database of exotic fish records. *Scientific Data, 9*(1), 363. doi: 10.1038/s41597-022-01487-z

Báez J. C., Pennino M. G., Albo-Puigserver M., Coll M., Giraldez A., and Bellido J. M. (2022). Effects of environmental conditions and jellyfish blooms on small pelagic fish and fisheries from the Western Mediterranean Sea. *Estuarine, Coastal and Shelf Science, 264*, 107699. doi: 10.1016/j.ecss.2021.107699

Basili R., Brizuela B., Herrero A., Iqbal S., Lorito S., Maesano F. E., Murphy S., Perfetti P., Romano F., Scala A., Selva J., Taroni M., Tiberti M. M., Thio H. K., Tonini R., Volpe M., Glimsdal S., Harbitz C. B., Løvholt F., ... Zaytsev A. (2021). The Making of the NEAM Tsunami Hazard Model 2018 (NEAMTHM18). *Frontiers in Earth Science, 8*, 616594. doi: 10.3389/feart.2020.616594

Baudena A., Ser-Giacomi E., Jalón-Rojas I., Galgani F., and Pedrotti M. L. (2022). The streaming of plastic in the Mediterranean Sea. *Nature Communications, 13*(1), 2981. doi: 10.1038/s41467-022-30572-5

Belivermiş M., Kılıç Ö., and Çotuk Y. (2016). Assessment of metal concentrations in indigenous and caged mussels *(Mytilus galloprovincialis)* on entire Turkish coastline. *Chemosphere, 144,* 1980–1987. doi: 10.1016/j.chemosphere.2015.10.098

Belušić Vozila A., Güttler I., Ahrens B., Obermann-Hellhund A., and Telišman Prtenjak M. (2019). Wind Over the Adriatic Region in CORDEX Climate Change Scenarios. *Journal of Geophysical Research: Atmospheres, 124*(1), 110–130. doi: 10.1029/2018jd028552

Ben Rais Lasram F., Guilhaumon F., Albouy C., Somot S., Thuiller W., and Mouillot D. (2010). The Mediterranean Sea as a 'cul-de-sac' for endemic fishes facing climate change. *Global Change Biology, 16*(12), 3233–3245. doi: 10.1111/j.1365-2486.2010.02224.x

Benedicto J., Andral B., Martínez-Gómez C., Guitart C., Deudero S., Cento A., Scarpato A., Caixach J., Benbrahim S., Chouba L., Boulahdid M., and Galgani F. (2011). A large scale survey of trace metal levels in coastal waters of the Western Mediterranean basin using caged mussels (Mytilus galloprovincialis). *Journal of Environmental Monitoring, 13*(5). doi: 10.1039/c0em00725k

Besset M., Anthony E. J., and Sabatier F. (2017). River delta shoreline reworking and erosion in the Mediterranean and Black Seas: The potential roles of fluvial sediment starvation and other factors. *Elementa, 5.* doi: 10.1525/elementa.139/112409

Beusen A. H. W., Bouwman A. F., Beek L. P. H. Van, Mogollón J. M., and Middelburg J. J. (2016). Global riverine N and P transport to ocean increased during the 20th century despite increased retention along the aquatic continuum. *Biogeosciences, 13*(8). doi: 10.5194/bg-13-2441-2016

Bevacqua E., De Michele C., Manning C., Couasnon A., Ribeiro A. F. S., Ramos A. M., Vignotto E., Bastos A., Blesić S., Durante F., Hillier J., Oliveira S. C., Pinto J. G., Ragno E., Rivoire P., Saunders K., van der Wiel K., Wu W., Zhang T., and Zscheischler J. (2021). Guidelines for Studying Diverse Types of Compound Weather and Climate Events. *Earth's Future, 9*(11). doi: 10.1029/2021ef002340

Bevacqua E., Vousdoukas M. I., Zappa G., Hodges K., Shepherd T. G., Maraun D., Mentaschi L., and Feyen L. (2020). More meteorological events that drive compound coastal flooding are projected under climate change. *Communications Earth & Environment, 1*(1), 47. doi: 10.1038/s43247-020-00044-z

Bianchi C. N., Azzola A., Bertolino M., Betti F., Bo M., Cattaneo-Vietti R., Cocito S., Montefalcone M., Morri C., Oprandi A., Peirano A., and Bavestrello G. (2019). Consequences of the marine climate and ecosystem shift of the 1980-90s on the Ligurian Sea biodiversity (NW Mediterranean). *The European Zoological Journal, 86(1), 458*–487. doi: 10.1080/24750263.2019.1687765

Bianchi C. N., and Morri C. (2003). Global sea warming and "tropicalization" of the Mediterranean Sea: biogeographic and ecological aspects. Biogeographia – *The Journal of Integrative Biogeography, 24*(1). doi: 10.21426/b6110129

Bilbao J., Román R., and De Miguel A. (2019). Temporal and Spatial Variability in Surface Air Temperature and Diurnal Temperature Range in Spain over the Period 1950–2011. *Climate, 7*(1), 16. doi: 10.3390/cli7010016

Billen G., Silvestre M., Grizzetti B., Leip A., Garnier J., Voss M., Howarth R., Bouraoui F., Lepistö A., Kortelainen P., Johnes P., Curtis C., Humborg C., Smedberg E., Kaste Ø., Ganeshram R., Beusen A., and Lancelot C. (2011). Nitrogen flows from European regional watersheds to coastal marine waters. *The European Nitrogen Assessment,* 271–297. doi: 10.1017/CBO9780511976988.016

Boberg F., and Christensen J. H. (2012). Overestimation of Mediterranean summer temperature projections due to model deficiencies. *Nature Climate Change, 2*(6), 433–436. doi: 10.1038/nclimate1454

Boero F. (2013). Review of jellyfish blooms in the Mediterranean and Black Sea. In *United Nations Human Settlements Programme (UN-Habitat): Addis Ababa, Ethiopia. (2021).* FAO, Rome, Italy. https://openknowledge.fao.org/handle/20.500.14283/i3169e

Boero F., Bouillon J., Gravili C., Miglietta M., Parsons T., and Piraino S. (2008). Gelatinous plankton: irregularities rule the world (sometimes). *Marine Ecology Progress Series, 356*, 299–310. doi: 10.3354/meps07368

Boucher, J. & Bilard, G. (2020). *The Mediterranean: Mare plasticum.* Gland, Switzerland: IUCN. x+62 pp. https://portals.iucn.org/library/sites/library/files/documents/2020-030-En.pdf

Brotz L. (2011). *Changing jellyfish populations : trends in large marine ecosystems.* doi: 10.14288/1.0053266

Brotz L., Cheung W. W. L., Kleisner K., Pakhomov E., and Pauly D. (2012). Increasing jellyfish populations: trends in Large Marine Ecosystems. In J. Purcell, H. Mianzan, & J. R. Frost (Eds.), *Jellyfish Blooms IV* (pp. 3–20). Springer Netherlands. https://link.springer.com/10.1007/978-94-007-5316-7_2

Brotz L., and Pauly D. (2012). Jellyfish populations in the Mediterranean Sea. *Acta Adriatica, 53*(2), 213–232. https://acta.izor.hr/ojs/index.php/acta/article/view/322

Brumovský M., Bečanová J., Kohoutek J., Borghini M., and Nizzetto L. (2017). Contaminants of emerging concern in the open sea waters of the Western Mediterranean. *Environmental Pollution, 229*. doi: 10.1016/j.envpol.2017.07.082

Caiola N., and Sostoa A. (2005). Possible reasons for the decline of two native toothcarps in the Iberian Peninsula: evidence of competition with the introduced Eastern mosquitofish. *Journal of Applied Ichthyology, 21*(4), 358–363. doi: 10.1111/j.1439-0426.2005.00684.x

Calabrese A., Luciani P., and Perini L. (2021). *A review of impact of subsidence induced by gas exploitation on costal erosion in Emilia Romagna, Italy. 62*, 279–300. doi: 10.4430/bgta0356

Caloiero T., Caloiero P., and Frustaci F. (2018). Long-term precipitation trend analysis in Europe and in the Mediterranean basin. *Water and Environment Journal, 32*(3), 433–445. doi: 10.1111/wej.12346

Caloiero T., Veltri S., Caloiero P., and Frustaci F. (2018). Drought Analysis in Europe and in the Mediterranean Basin Using the Standardized Precipitation Index. *Water 2018, Vol. 10, Page 1043*, 10(8). doi: 10.3390/w10081043

Camerlenghi A., Urgeles R., and Fantoni L. (2010). A Database on Submarine Landslides of the Mediterranean Sea. In D. C. Mosher, R. C. Shipp, L. Moscardelli, J. D. Chaytor, C. D. P. Baxter, H. J. Lee, & R. Urgeles (Eds.), *Submarine Mass Movements and Their Consequences* (pp. 503–513). Springer Netherlands. http://link.springer.com/10.1007/978-90-481-3071-9_41

Camuffo D. (2021). Four centuries of documentary sources concerning the sea level rise in Venice. *Climatic Change, 167*(3–4), 54. doi: 10.1007/s10584-021-03196-9

Camuffo D. (2022a). A discussion on sea level rise, rate and acceleration. Venice as a case study. *Environmental Earth Sciences, 81*(13), 349. doi: 10.1007/s12665-022-10482-x

Camuffo D. (2022b). Historical Documents as Proxy Data in Venice and Its Marine Environment. *Oxford Research Encyclopedia of Climate Science*. doi: 10.1093/acrefore/9780190228620.013.875

Camuffo D. (2023). The Treatise on Waters by Cornaro (1560) and a quantitative assessment of the historical sea surges "Acqua Alta" in Venice. *Climatic Change, 176*(3), 18. doi: 10.1007/s10584-023-03492-6

Camuffo D., Bertolin C., and Schenal P. (2017). A novel proxy and the sea level rise in Venice, Italy, from 1350 to 2014. *Climatic Change, 143*(1–2), 73–86. doi: 10.1007/s10584-017-1991-3

Canepa A., Fuentes V., Sabatés A., Piraino S., Boero F., and Gili J.-M. (2014). Pelagia noctiluca in the Mediterranean Sea. In K. A. Pitt & C. H. Lucas (Eds.), *Jellyfish Blooms* (pp. 237–266). Springer, Dordrecht doi: 10.1007/978-94-007-7015-7_11

Carpenter A., and Kostianoy A. G. (2018). Oil Pollution in the Mediterranean Sea: Part I. The International Context. In A. Carpenter & A. G. Kostianoy (Eds.), *The Handbook of Environmental Chemistry* (Vol. 83). Springer Cham. doi: 10.1007/978-3-030-12236-2

Carpenter B. (2004). Feeling the sting. *U.S. News & World Report, 137*(5), 68–69. https://pubmed.ncbi.nlm.nih.gov/15352737/

Casas D., Ercilla G., Yenes M., Estrada F., Alonso B., García M., and Somoza L. (2011). The Baraza Slide: Model and dynamics. *Marine Geophysical Research, 32*(1), 245–256. doi: 10.1007/s11001-011-9132-2

Cavicchia L., von Storch H., and Gualdi S. (2014). Mediterranean Tropical-Like Cyclones in Present and Future Climate. *Journal of Climate, 27*(19), 7493–7501. doi: 10.1175/jcli-d-14-00339.1

Cazenave A., and Moreira L. (2022). Contemporary sea-level changes from global to local scales: A review. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 478*(2261). doi: 10.1098/rspa.2022.0049

CEAM (2019). *Mediterranean Sea Surface Temperature report (Spring 2019).* Meteorology and Pollutant Dynamics Area. Fundación CEAM. 2019. doi: 10.13140/rg.2.2.35354.08648

CEAM (2021). *Mediterranean Sea Surface Temperature report (Summer 2021).* Meteorology and Pollutant Dynamics Area. Fundación CEAM. doi: 10.13140/rg.2.2.27205.99048

Chacón L., Reyes L., Rivera-Montero L., and Barrantes K. (2022). Transport, fate, and bioavailability of emerging pollutants in soil, sediment, and wastewater treatment plants: Potential environmental impacts. *Emerging Contaminants in the Environment: Challenges and Sustainable Practices* (pp 111-136). doi: 10.1016/B978-0-323-85160-2.00020-2

Champagne P., Dorgham M. M., Liang S., Favreau G., and Shaaban N. A. (2021). Time series relationships between chlorophyll-a, physicochemical parameters, and nutrients in the Eastern Harbour of Alexandria, Egypt. *Environmental Monitoring and Assessment, 193*(12), 1–15. doi: 10.1007/s10661-021-09604-y

Chatzimentor A., Doxa A., Katsanevakis S., and Mazaris A. D. (2023). Are Mediterranean marine threatened species at high risk by climate change? *Global Change Biology, 29*(7). doi: 10.1111/gcb.16577

Cherif S., Doblas-Miranda E., Lionello P., Borrego C., Giorgi F., Iglesias A., Jebari S., Mahmoudi E., Moriondo M., Pringault O., Rilov G., Somot S., Tsikliras A., Vila M., and Zittis G. (2020). Drivers of change. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental Change in the Mediterranean Basin–Current Situation and Risks for the Future. First Mediterranean Assessment Report.* Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, pp. 59-180. doi: 10.5281/zenodo.7100601

Cheung W. W. L., Jones M. C., Reygondeau G., Stock C. A., Lam V. W. Y., and Frölicher T. L. (2016). Structural uncertainty in projecting global fisheries catches under climate change. *Ecological Modelling, 325,* 57–66. doi: 10.1016/j.ecolmodel.2015.12.018

Christodoulou A., Christidis P., and Demirel H. (2019). Sea-level rise in ports: a wider focus on impacts. *Maritime Economics & Logistics, 21*(4), 482–496. doi: 10.1057/s41278-018-0114-z

Christodoulou A., and Demirel H. (2018). Impacts of climate change on transport - A focus on airports, seaports and inland waterways. In *Publications Office of the European Union, Lubembourg.* doi: 10.2760/378464

CIESM (2011). Marine Geohazards in the Mediterranean: an overview. In F. Briand (Ed.), *Marine geohazards in the Mediterranean. N° 42 in CIESMWorkshop Monographs. CIESM, Monaco,* 192 pp. https://www.researchgate.net/publication/272164711_Marine_Geohazards_in_the_Mediterranean_an_overview

CLIA (2022). *State of the cruise industry. Outlook.* https://cruising.org/sites/default/files/2025-03/CLIA-State-Of-The-Cruise-Industry-2022_updated.pdf

Coll M., Piroddi C., Steenbeek J., Kaschner K., Ben Rais Lasram F., Aguzzi J., Ballesteros E., Bianchi C. N., Corbera J., Dailianis T., Danovaro R., Estrada M., Froglia C., Galil B. S., Gasol J. M., Gertwagen R., Gil J., Guilhaumon F., Kesner-Reyes K., … Voultsiadou E. (2010). The Biodiversity of the Mediterranean Sea: Estimates, Patterns, and Threats. *PLoS ONE, 5(8),* e11842. doi: 10.1371/journal.pone.0011842

Combi T., Pintado-Herrera M. G., Lara-Martín P. A., Lopes-Rocha M., Miserocchi S., Langone L., and Guerra R. (2020). Historical sedimentary deposition and flux of PAHs, PCBs and DDTs in sediment cores from the western Adriatic Sea. *Chemosphere, 241.* doi: 10.1016/j.chemosphere.2019.125029

Condon R. H., Duarte C. M., Pitt K. A., Robinson K. L., Lucas C. H., Sutherland K. R., Mianzan H. W., Bogeberg M., Purcell J. E., Decker M. B., Uye S., Madin L. P., Brodeur R. D., Haddock S. H. D., Malej A., Parry G. D., Eriksen E., Quiñones J., Acha M., … Graham W. M. (2013). Recurrent jellyfish blooms are a consequence of global oscillations. *Proceedings of the National Academy of Sciences, 110*(3), 1000–1005. doi: 10.1073/pnas.1210920110

Contini D., and Merico E. (2021). Recent advances in studying air quality and health effects of shipping emissions. *Atmosphere, 12*(1). doi: 10.3390/atmos12010092

Cooley, S., D. Schoeman, L. Bopp, P. Boyd, S. Donner, D.Y. Ghebrehiwet, S.-I. Ito, W. Kiessling, P. Martinetto, E. Ojea, M.-F. Racault, B. Rost, and M. Skern-Mauritzen, 2022: Oceans and Coastal Ecosystems and Their Services. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 379–550. doi: 10.1017/9781009325844.005

Corrales X., Coll M., Ofir E., Heymans J. J., Steenbeek J., Goren M., Edelist D., and Gal G. (2018). Future scenarios of marine resources and ecosystem conditions in the Eastern Mediterranean under the impacts of fishing, alien species and sea warming. *Scientific Reports, 8*(1), 14284. doi: 10.1038/s41598-018-32666-x

Cos J., Doblas-Reyes F., Jury M., Marcos R., Bretonnière P. A., and Samsó M. (2022). The Mediterranean climate change hotspot in the CMIP5 and CMIP6 projections. *Earth System Dynamics, 13*(1), 321–340. doi: 10.5194/esd-13-321-2022

Cossa D., Knoery J., B-naru D., Harmelin-Vivien M., Sonke J. E., Hedgecock I. M., Bravo A. G., Rosati G., Canu D., Horvat M., Sprovieri F., Pirrone N., and Heimbürger-Boavida L. E. (2022). Mediterranean Mercury Assessment 2022: An Updated Budget, Health Consequences, and Research Perspectives. *Environmental Science and Technology, 56*(7). doi: 10.1021/acs.est.1c03044

Cózar A., Sanz-Martín M., Martí E., González-Gordillo J. I., Ubeda B., Gálvez J. Á., Irigoien X., and Duarte C. M. (2015). Plastic Accumulation in the Mediterranean Sea. *PLOS ONE, 10*(4), e0121762. doi: 10.1371/journal.pone.0121762

d'Acremont E., Lafuerza S., Rabaute A., Lafosse M., Jollivet Castelot M., Gorini C., Alonso B., Ercilla G., Vazquez J. T., Vandorpe T., Juan C., Migeon S., Ceramicola S., Lopez-Gonzalez N., Rodriguez M., El Moumni B., Benmarha O., and Ammar A. (2022). Distribution and origin of submarine landslides in the active margin of the southern Alboran Sea (Western Mediterranean Sea). *Marine Geology, 445*, 106739. doi: 10.1016/j.margeo.2022.106739

Dafka S., Toreti A., Zanis P., Xoplaki E., and Luterbacher J. (2019). Twenty-First-Century Changes in the Eastern Mediterranean Etesians and Associated Midlatitude Atmospheric Circulation. *Journal of Geophysical Research: Atmospheres, 124*(23), 12741–12754. doi: 10.1029/2019jd031203

D'Agostino R., and Lionello P. (2020). The atmospheric moisture budget in the Mediterranean: Mechanisms for seasonal changes in the Last Glacial Maximum and future warming scenario. Quaternary Science Reviews, 241, 106392. doi: 10.1016/j.quascirev.2020.106392

D'Agostino R., Lionello P., Adam O., and Schneider T. (2017). Factors controlling Hadley circulation changes from the Last Glacial Maximum to the end of the 21st century. *Geophysical Research Letters, 44*(16), 8585–8591. doi: 10.1002/2017gl074533

D'Agostino R., Scambiati A. L., Jungclaus J., and Lionello P. (2020). Poleward Shift of Northern Subtropics in Winter: Time of Emergence of Zonal Versus Regional Signals. *Geophysical Research Letters, 47*(19). doi: 10.1029/2020gl089325

Dakhlaoui H., Hakala K., and Seibert J. (2022). Hydrological Impacts of Projected Climate Change on Northern Tunisian Headwater Catchments—An Ensemble Approach Addressing Uncertainties. In W. Leal Filho & E. Manolas (Eds.), *Climate Change in the Mediterranean and Middle Eastern Region* (pp. 499–519). Springer International Publishing. doi: 10.1007/s10113-020-01615-8

Dakhlaoui H., Seibert J., and Hakala K. (2020). Sensitivity of discharge projections to potential evapotranspiration estimation in Northern Tunisia. *Regional Environmental Change, 20*(2), 34. doi: 10.1007/s10113-020-01615-8

Dalyan C., Yemişken E., and Eryilmaz L. (2012). A new record of gaper (Champsodon capensis Regan, 1908) in the Mediterranean Sea. *Journal of Applied Ichthyology, 28*(5), 834. doi: 10.1111/J.1439-0426.2012.02019.x

Darmaraki S., Somot S., Sevault F., and Nabat P. (2019a). Past Variability of Mediterranean Sea Marine Heatwaves. *Geophysical Research Letters, 46*(16), 9813–9823. doi: 10.1029/2019gl082933

Darmaraki S., Somot S., Sevault F., Nabat P., Cabos Narvaez W. D., Cavicchia L., Djurdjevic V., Li L., Sannino G., and Sein D. V. (2019b). Future evolution of Marine Heatwaves in the Mediterranean Sea. *Climate Dynamics, 53*(3–4), 1371–1392. doi: 10.1007/s00382-019-04661-z

De Leo F., Besio G., and Mentaschi L. (2021). Trends and variability of ocean waves under RCP8.5 emission scenario in the Mediterranean Sea. *Ocean Dynamics, 71*(1), 97–117. doi: 10.1007/s10236-020-01419-8

Dell'Aquila A., Mariotti A., Bastin S., Calmanti S., Cavicchia L., Deque M., Djurdjevic V., Dominguez M., Gaertner M., and Gualdi S. (2018). Evaluation of simulated decadal variations over the Euro-Mediterranean region from ENSEMBLES to Med-CORDEX. *Climate Dynamics, 51*(3), 857–876. doi: 10.1007/s00382-016-3143-2

Desbiolles F., Malleret L., Tiliacos C., Wong-Wah-Chung P., and Laffont-Schwob I. (2018). Occurrence and ecotoxicological assessment of pharmaceuticals: Is there a risk for the Mediterranean aquatic environment? *Science of the Total Environment, 639*. doi: 10.1016/j.scitotenv.2018.04.351

Di Leo A., Annicchiarico C., Cardellicchio N., Giandomenico S., Conversano M., Castellano G., Basile F., Martinelli W., Scortichini G., and Spada L. (2014). Monitoring of PCDD/Fs and dioxin-like PCBs and seasonal variations in mussels from the Mar Grande and the Mar Piccolo of Taranto (Ionian Sea, Southern Italy). *Environmental Science and Pollution Research, 21*(23). doi: 10.1007/s11356-014-2495-6

Di Paola G., Rizzo A., Benassai G., Corrado G., Matano F., and Aucelli P. P. C. (2021). Sea-level rise impact and future scenarios of inundation risk along the coastal plains in Campania (Italy). *Environmental Earth Sciences, 80*(17), 608. doi: 10.1007/s12665-021-09884-0

Dimitriadis C., Fournari-Konstantinidou I., Sourbès L., Koutsoubas D., and Katsanevakis S. (2021). Long Term Interactions of Native and Invasive Species in a Marine Protected Area Suggest Complex Cascading Effects Challenging Conservation Outcomes. *Diversity, 13*(2), 71. doi: 10.3390/d13020071

Distefano S., Baldassini N., Barbagallo V., Borzì L., D'Andrea N. M., Urso S., and Di Stefano A. (2022). 3D Flooding Maps as Response to Tsunami Events: Applications in the Central Sicilian Channel (Southern Italy). *Journal of Marine Science and Engineering 2022, Vol. 10, Page 1953, 10*(12), 1953. doi: 10.3390/jmse10121953

Dorgham M., El-Tohamy W., Qin J., Abdel-Aziz N., and Ghobashy A. (2019). Water quality assessment of the Nile Delta Coast, south eastern Mediterranean, Egypt. *Egyptian Journal of Aquatic Biology and Fisheries, 23*(3), 151–169. doi: 10.21608/ejabf.2019.45019

dos Santos M., Moncada S., Elia A., Grillakis M., and Hilmi N. (2020). Society: Development. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report.* Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, pp. 469-492. doi: 10.5281/zenodo.7101111

Doussin J.-F. (2023). The Mediterranean Atmosphere Under Anthropogenic Pressures. In *Atmospheric Chemistry in the Mediterranean Region.* doi: 10.1007/978-3-031-12741-0_4

Downie A. T., Illing B., Faria A. M., and Rummer J. L. (2020). Swimming performance of marine fish larvae: review of a universal trait under ecological and environmental pressure. *Reviews in Fish Biology and Fisheries, 30*(1), 93–108. doi: 10.1007/s11160-019-09592-w

Drira Z., Kmiha-Megdiche S., Sahnoun H., Hammami A., Allouche N., Tedetti M., and Ayadi H. (2016). Assessment of anthropogenic inputs in the surface waters of the southern coastal area of Sfax during spring (Tunisia, Southern Mediterranean Sea). *Marine Pollution Bulletin, 104*(1–2). doi: 10.1016/j.marpolbul.2016.01.035

Droogers P., Immerzeel W. W., Terink W., Hoogeveen J., Bierkens M. F. P., Van Beek L. P. H., and Debele B. (2012). Water resources trends in Middle East and North Africa towards 2050. *Hydrology and Earth System Sciences, 16*(9), 3101–3114. doi: 10.5194/hess-16-3101-2012

Dubois C., Somot S., Calmanti S., Carillo A., Déqué M., Dell'Aquilla A., Elizalde A., Gualdi S., Jacob D., L'Hévéder B., Li L., Oddo P., Sannino G., Scoccimarro E., and Sevault F. (2012). Future projections of the surface heat and water budgets of the Mediterranean Sea in an ensemble of coupled atmosphere–ocean regional climate models. *Climate Dynamics, 39*(7–8), 1859–1884. doi: 10.1007/s00382-011-1261-4

Dulac F., Sauvage S., and Hamonou E. (2022). Atmospheric chemistry in the Mediterranean region. In *Atmospheric Chemistry in the Mediterranean Region (Vol. 2).* doi: 10.1007/978-3-030-82385-6

EC (2004). Part I—Major Findings and Policy Recommendations of the EUROSION Project. Living With Coastal Erosion in Europe: Sediment and Space for Sustainability. Official Publications of the European Communities, Luxembourg, 57. http://www.eurosion.org/reports-online/reports.html

EC (2006). *Commission Regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs.* Official Journal of the European Union, L 364, 5–24. https://eur-lex.europa.eu/eli/reg/2006/1881

EC: Directorate-General for Maritime Affairs and Fisheries, Addamo A. M., Calvo Santos A., Guillén J., and Guillén J., N. S. et al. (2022). *The EU blue economy report 2022.* Publications Office of the European Union. doi: 10.2771/793264

Edelist D., Rilov G., Golani D., Carlton J. T., and Spanier E. (2013). Restructuring the Sea: profound shifts in the world's most invaded marine ecosystem. *Diversity and Distributions, 19*(1), 69–77. doi: 10.1111/ddi.12002

EEA (2016). Dams on larger rivers in Europe, available at https://www.eea.europa.eu/data-and-maps/figures/dams-with-reservoirs-on-rivers

EEA (2021). Sources and emissions of air pollutants in Europe - European Environment Agency. European Environmental Agency. https://www.eea.europa.eu/publications/air-quality-in-europe-2021/sources-and-emissions-of-air

EEA (2022a). *Air quality in Europe 2022.* European Environmental Agency doi: 10.2800/488115

EEA (2022b). *Oxygen concentrations in coastal and marine waters surrounding Europe.* https://www.eea.europa.eu/ims/oxygen-concentrations-in-coastal-and

EEA-UNEP/MAP (2021). *Technical assessment of progress towards a cleaner Mediterranean Monitoring and reporting results for Horizon 2020 regional initiative.* Publications Office of the European Union. https://data.europa.eu/doi/10.2800/898759

Elguindi N., Somot S., Déqué M., and Ludwig W. (2011). Climate change evolution of the hydrological balance of the Mediterranean, Black and Caspian Seas: impact of climate model resolution. *Climate Dynamics, 36*(1–2), 205–228. doi: 10.1007/s00382-009-0715-4

EMSA (2021). *European Maritime Transport Environmental Report 2021.* Luxembourg: Publications Office of the European Union, 2019. https://www.emsa.europa.eu/emter-2021.html

Ezber Y. (2019). Assessment of the changes in the Etesians in the EURO-CORDEX regional model projections. *International Journal of Climatology, 39*(3), 1213–1229. doi: 10.1002/joc.5872

FAO (2016). Livestock contribution to food security in the Near East and North Africa. *FAO regional conference for the Near East, 33rd Session,* Beirut, Lebanon, 18-22 April 2016. https://openknowledge.fao.org/server/api/core/bitstreams/78b4f304-b687-4069-a5de-21f6c25d31ed/content

FAO (2023). Fisheries Glossary. In *Fisheries and Aquaculture.* [online] https://www.fao.org/fishery/en/collection/glossary_fisheries

FAO, IFAD, UNICEF, WFP, and WHO (2022). *The State of the World's Land and Water Resources for Food and Agriculture 2021 – Systems at breaking point. Main report.* Rome, FAO. doi: 10.4060/cb9910en

Fenoglio-Marc L., Mariotti A., Sannino G., Meyssignac B., Carillo A., Struglia M. V, and Rixen M. (2013). Decadal variability of net water flux at the Mediterranean Sea Gibraltar Strait. *Global and Planetary Change, 100*, 1–10. doi: 10.1016/j.gloplacha.2012.08.007

Fink L., Karl M., Matthias V., Oppo S., Kranenburg R., Kuenen J., Moldanova J., Jutterstrom S., Jalkanen J. P., and Majamaki E. (2023). Potential impact of shipping on air pollution in the Mediterranean region - A multimodel evaluation: Comparison of photooxidants NO_2 and O_3. *Atmospheric Chemistry and Physics, 23*(3). doi: 10.5194/acp-23-1825-2023

Flecha S., Pérez F. F., Murata A., Makaoui A., and Huertas I. E. (2019). Decadal acidification in Atlantic and Mediterranean water masses exchanging at the Strait of Gibraltar. *Scientific Reports, 9*(1), 15533. doi: 10.1038/s41598-019-52084-x

Fox-Kemper B., Hewitt H. T., Xiao C., Aðalgeirsdóttir G., Drijfhout S. S., Edwards T. L., Golledge N. R., Hemer M., Kopp R. E., Krinner G., Mix A., Notz D., Nowicki S., Nurhati I. S., Ruiz L., Sallée J.-B., Slangen A. B. A., and Yu Y. (2021). Ocean, cryosphere, and sea level change. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, Ö. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1211–1362. doi: 10.1017/9781009157896.011

Friedrich W. L., Kromer B., Friedrich M., Heinemeier J., Pfeiffer T., and Talamo S. (2006). Santorini Eruption Radiocarbon Dated to 1627-1600 B.C. *Science, 312*(5773), 548. doi: 10.1126/science.1125087

Frihy O. E., and Stanley J.-D. (2023). The Modern Nile Delta Continental Shelf, with an Evolving Record of Relict Deposits Displaced and Altered by Sediment Dynamics. *Geographies, 3*(3), 416–445. doi: 10.3390/geographies3030022

Gaertner M. A., Jacob D., Gil V., Domínguez M., Padorno E., Sánchez E., and Castro M. (2007). Tropical cyclones over the Mediterranean Sea in climate change simulations. *Geophysical Research Letters, 34*(14), 14711. doi: 10.1029/2007gl029977

Galil B., Marchini A., Occhipinti-Ambrogi A., and Ojaveer H. (2017). The enlargement of the Suez Canal—Erythraean introductions and management challenges. *Management of Biological Invasions, 8*(2), 141–152. doi: 10.3391/mbi.2017.8.2.02

Ganora D., Dorati C., Huld T. A., Udias A., and Pistocchi A. (2019). An assessment of energy storage options for large-scale PV-RO desalination in the extended Mediterranean region. *Scientific Reports, 9*(1), 16234. doi: 10.1038/s41598-019-52582-y

García-Gómez J. C., Sempere-Valverde J., González A. R., Martínez-Chacón M., Olaya-Ponzone L., Sánchez-Moyano E., Ostalé-Valriberas E., and Megina C. (2020). From exotic to invasive in record time: The extreme impact of Rugulopteryx okamurae (Dictyotales, Ochrophyta) in the strait of Gibraltar. *Science of The Total Environment, 704*, 135408. doi: 10.1016/j.scitotenv.2019.135408

Georgiou G. K., Christoudias T., Proestos Y., Kushta J., Pikridas M., Sciare J., Savvides C., and Lelieveld J. (2022). Evaluation of WRF-Chem model (v3.9.1.1) real-Time air quality forecasts over the Eastern Mediterranean. *Geoscientific Model Development, 15*(10). doi: 10.5194/gmd-15-4129-2022

Glibert P. M. (2017). Eutrophication, harmful algae and biodiversity — Challenging paradigms in a world of complex nutrient changes. *Marine Pollution Bulletin, 124*(2). doi: 10.1016/j.marpolbul.2017.04.027

Golani D., Azzurro E., Dulčić J., Massutí E., and Orsi-Relini L. (2021). *Atlas of Exotic Fishes in the Mediterranean Sea* (F. Briand, Ed.). CIESM Publishers, Paris, Monaco.

Gollasch S., Hewitt C. L., Bailey S., and David M. (2019). Introductions and transfers of species by ballast water in the Adriatic Sea. *Marine Pollution Bulletin, 147*, 8–15. doi: 10.1016/j.marpolbul.2018.08.054

González-Alemán J. J., Pascale S., Gutierrez-Fernandez J., Murakami H., Gaertner M. A., and Vecchi G. A. (2019). Potential Increase in Hazard From Mediterranean Hurricane Activity With Global Warming. *Geophysical Research Letters, 46*(3), 1754–1764. doi: 10.1029/2018gl081253

González-Fernández D., Cózar A., Hanke G., Viejo J., Morales-Caselles C., Bakiu R., Barceló D., Bessa F., Bruge A., Cabrera M., Castro-Jiménez J., Constant M., Crosti R., Galletti Y., Kideys A. E., Machitadze N., Pereira de Brito J., Pogojeva M., Ratola N., … Tourgeli M. (2021). Floating macrolitter leaked from Europe into the ocean. *Nature Sustainability, 4*(6). doi: 10.1038/s41893-021-00722-6

Goyet C., Hassoun A., Gemayel E., Touratier F., Abboud-Abi Saab M., and Guglielmi V. (2016). Thermodynamic Forecasts of the Mediterranean Sea Acidification. *Mediterranean Marine Science, 17*(2), 508. doi: 10.12681/mms.1487

Grillakis M. G. (2019). Increase in severe and extreme soil moisture droughts for Europe under climate change. *Science of The Total Environment, 660*, 1245–1255. doi: 10.1016/j.scitotenv.2019.01.001

Grise K. M., Davis S. M., Simpson I. R., Waugh D. W., Fu Q., Allen R. J., Rosenlof K. H., Ummenhofer C. C., Karnauskas K. B., Maycock A. C., Quan X.-W., Birner T., and Staten P. W. (2019). Recent Tropical Expansion: Natural Variability or Forced Response? *Journal of Climate, 32*(5), 1551–1571. doi: 10.1175/jcli-d-18-0444.1

Grosholz E. (2002). Ecological and evolutionary consequences of coastal invasions. In *Trends in Ecology and Evolution, 17*(1), 22-27. doi: 10.1016/S0169-5347(01)02358-8

Gudmundsson L., and Seneviratne S. I. (2016). Anthropogenic climate change affects meteorological drought risk in Europe. *Environmental Research Letters, 11*(4). doi: 10.1088/1748-9326/11/4/044005

Guidoboni E., Ferrari G., Mariotti D., Comastri A., Tarabusi G., Sgattoni G., and Valensise G. (2018). Historical earthquake data from the CFTI5Med catalogue [dataset publication series]. *PANGAEA*. doi: 10.1594/pangaea.896754

Guidoboni E., Ferrari G., Tarabusi G., Sgattoni G., Comastri A., Mariotti D., Ciuccarelli C., Bianchi M. G., and Valensise G. (2019). CFTI5Med, the new release of the catalogue of strong earthquakes in Italy and in the Mediterranean area. *Scientific Data, 6*(1), 80. doi: 10.1038/s41597-019-0091-9

Gutiérrez J. M., Jones R. G., G.T. Narisma G. T., Alves L. M., Amjad M., Gorodetskaya I. V., Grose M., Klutse N. A. B., Krakovska S., Li J., Martínez-Castro D., Mearns L. O., Mernild S. H., Ngo-Duc T., van den Hurk B., and Yoon J.-H. (2021). Atlas. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1927–2058. doi: 10.1017/9781009157896.021

Hallegraeff G. M. (2010). Ocean Climate Change, Phytoplankton Community Responses, and Harmful Algal Blooms: A Formidable Predictive Challenge. *Journal of Phycology, 46*(2), 220–235. doi: 10.1111/j.1529-8817.2010.00815.x

Hall-Spencer J. M., and Harvey B. P. (2019). Ocean acidification impacts on coastal ecosystem services due to habitat degradation. *Emerging Topics in Life Sciences, 3*(2), 197–206. doi: 10.1042/etls20180117

Hassoun A. E. R., Bantelman A., Canu D., Comeau S., Galdies C., Gattuso J.-P., Giani M., Grelaud M., Hendriks I. E., Ibello V., Idrissi M., Krasakopoulou E., Shaltout N., Solidoro C., Swarzenski P. W., and Ziveri P. (2022). Ocean acidification research in the Mediterranean Sea: Status, trends and next steps. *Frontiers in Marine Science, 9*. doi: 10.3389/fmars.2022.892670

Hertig E., and Tramblay Y. (2017). Regional downscaling of Mediterranean droughts under past and future climatic conditions. *Global and Planetary Change, 151*, 36–48. doi: 10.1016/j.gloplacha.2016.10.015

Hidalgo García D., Arco Díaz J., Martín Martín A., and Gómez Cobos E. (2022). Spatiotemporal Analysis of Urban Thermal Effects Caused by Heat Waves through Remote Sensing. *Sustainability, 14*(19), 12262. doi: 10.3390/su141912262

Hueging H., Haas R., Born K., Jacob D., and Pinto J. G. (2013). Regional Changes in Wind Energy Potential over Europe Using Regional Climate Model Ensemble Projections. *Journal of Applied Meteorology and Climatology, 52*(4), 903–917. doi: 10.1175/jamc-d-12-086.1

Iacarella J. C., Lyons D. A., Burke L., Davidson I. C., Therriault T. W., Dunham A., and DiBacco C. (2020). Climate change and vessel traffic create networks of invasion in marine protected areas. *Journal of Applied Ecology, 57*(9), 1793–1805. doi: 10.1111/1365-2664.13652

Ibáñez C., and Peñuelas J. (2019). Changing nutrients, changing rivers. *Science, 365*(6454), 637–638. doi: 10.1126/science.aay2723

Ibrahim O., Mohamed B., and Nagy H. (2021). Spatial Variability and Trends of Marine Heat Waves in the Eastern Mediterranean Sea over 39 Years. *Journal of Marine Science and Engineering, 9*(6), 643. doi: 10.3390/jmse9060643

IPBES (2019). *Global assessment report on biodiversity and ecosystem services* (E. S. Brondizio, J. Settele, S. Díaz, & H. T. Ngo, Eds.). IPBES secretariat, Bonn, Germany. 1148 pages. doi: 10.5281/zenodo.3831673

IPCC (2021a). Annex VII: Glossary [Matthews, J.B.R., V. Möller, R. van Diemen, J.S. Fuglestvedt, V. Masson-Delmotte, C. Méndez, S. Semenov, A. Reisinger (eds.)]. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & and B. Zhou (Eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 2215–2256. doi: 10.1017/9781009157896.022

IPCC (2021b). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou, Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. doi: 10.1017/9781009157896

IPCC (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama, Eds.). Cambridge University Press. Cambridge, UK and New York, NY, USA, 3056 pp. doi: 10.1017/9781009325844

IPCC (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Core Writing Team, H. Lee, & J. Romero, Eds.). IPCC, Geneva, Switzerland, pp. 35-115. doi: 10.59327/IPCC/AR6-9789291691647

Jones M. C., and Cheung W. W. L. (2015). Multi-model ensemble projections of climate change effects on global marine biodiversity. *ICES Journal of Marine Science*, *72*(3), 741–752. doi: 10.1093/icesjms/fsu172

Justić D., Rabalais N. N., Turner R. E., and Dortch Q. (1995). Changes in nutrient structure of river-dominated coastal waters: Stoichiometric nutrient balance and its consequences. *Estuarine, Coastal and Shelf Science*, *40*(3). doi: 10.1016/S0272-7714(05)80014-9

Kanakidou M., Myriokefalitakis S., and Tsagkaraki M. (2020). Atmospheric inputs of nutrients to the Mediterranean Sea. *Deep Sea Research Part II: Topical Studies in Oceanography*, *171*, 104606. doi: 10.1016/j.dsr2.2019.06.014

Kaniewski D., Marriner N., Cheddadi R., Morhange C., Vacchi M., Rovere A., Faivre S., Otto T., Luce F., Carre M. B., Benčić G., and Van Campo E. (2021). Coastal submersions in the north-eastern Adriatic during the last 5200 years. *Global and Planetary Change*, *204*. doi: 10.1016/j.gloplacha.2021.103570

Kaniewski D., Marriner N., Vacchi M., Camuffo D., Bivolaru A., Sarti G., Bertoni D., Diatta L., Markakis N., Martella A., Otto T., Luce F., Calaon D., Cottica D., and Morhange C. (2024). Holocene Sea-level impacts on Venice Lagoon's coastal wetlands. *Global and Planetary Change*, *236*. doi: 10.1016/j.gloplacha.2024.104426

Kapsenberg L., Alliouane S., Gazeau F., Mousseau L., and Gattuso J.-P. (2017). Coastal ocean acidification and increasing total alkalinity in the northwestern Mediterranean Sea. *Ocean Science*, *13*(3), 411–426. doi: 10.5194/os-13-411-2017

Karydis M., and Kitsiou D. (2012). Eutrophication and environmental policy in the Mediterranean Sea: a review. *Environmental Monitoring and Assessment*, *184*(8), 4931–4984. doi: 10.1007/s10661-011-2313-2

Kasimati E., and Asero V. (2021). Cruise Tourism, Gender and Sustainability. In M. Valeri & V. Katsoni (Eds.), Gender and Tourism (pp. 37–53). Emerald Publishing Limited. doi: 10.1108/978-1-80117-322-320211003

Kateb A. El, Stalder C., Rüggeberg A., Neururer C., Spangenberg J. E., and Spezzaferri S. (2018). Impact of industrial phosphate waste discharge on the marine environment in the Gulf of Gabes (Tunisia). *PLOS ONE*, *13*(5), e0197731. doi: 10.1371/journal.pone.0197731

Kılıç S., Kılıç, Belivermiș M., and Ergül H. A. (2023). Chronology of PAH and PCB pollution using sediment core in the Golden Horn estuary (Sea of Marmara). *Marine Pollution Bulletin*, *187*. doi: 10.1016/j.marpolbul.2023.114570

Köck-Schulmeyer M., Ginebreda A., Petrovic M., Giulivo M., Aznar-Alemany Ò., Eljarrat E., Valle-Sistac J., Molins-Delgado D., Diaz-Cruz M. S., Monllor-Alcaraz L. S., Guillem-Argiles N., Martínez E., Miren L. de A., Llorca M., Farré M., Peña J. M., Mandaric L., Pérez S., Majone B., … Barceló D. (2021). Priority and emerging organic microcontaminants in three Mediterranean river basins: Occurrence, spatial distribution, and identification of river basin specific pollutants. *Science of the Total Environment*, *754*. doi: 10.1016/j.scitotenv.2020.142344

Kopp H., Chiocci F. L., Berndt C., Çağatay M. N., Ferreira T., Fortes C. J. E. M., Gràcia E., González Vega A., Kopf A. J., Sørensen M. B., Sultan N., and Yeo I. A. (2021). *Marine geohazards: Safeguarding society and the Blue Economy from a hidden threat* (A. Muñiz Piniella, P. Kellett, R. van den Brand, B. Alexander, A. Rodríguez Perez, J. Van Elslander, & J. J. Heymans, Eds.). Position Paper 26 of the European Marine Board, Ostend, Belgium. 100 pages. doi: 10.5281/zenodo.5591938

Lambert C., Authier M., Dorémus G., Laran S., Panigada S., Spitz J., Van Canneyt O., and Ridoux V. (2020). Setting the scene for Mediterranean litterscape management: The first basin-scale quantification and mapping of floating marine debris. *Environmental Pollution*, *263*. doi: 10.1016/j.envpol.2020.114430

Lassaletta L., Sanz-Cobena A., Aguilera E., Quemada M., Billen G., Bondeau A., Cayuela M. L., Cramer W., Eekhout J. P. C., Garnier J., Grizzetti B., Intrigliolo D. S., Ramos M. R., Romero E., Vallejo A., and Gimeno B. S. (2021). Nitrogen dynamics in cropping systems under Mediterranean climate: a systemic analysis. *Environmental Research Letters*, *16*(7), 073002. doi: 10.1088/1748-9326/ac002c

Lehner F., Coats S., Stocker T. F., Pendergrass A. G., Sanderson B. M., Raible C. C., and Smerdon J. E. (2017). Projected drought risk in 1.5°C and 2°C warmer climates. *Geophysical Research Letters*, *44*(14), 7419–7428. doi: 10.1002/2017gl074117

Lejeusne C., Chevaldonné P., Pergent-Martini C., Boudouresque C. F., and Pérez T. (2010). Climate change effects on a miniature ocean: the highly diverse, highly impacted Mediterranean Sea. *Trends in Ecology & Evolution*, *25*(4), 250–260. doi:10.1016/j.tree.2009.10.009

Lelieveld J., Berresheim H., Borrmann S., Crutzen P. J., Dentener F. J., Fischer H., Feichter J., Flatau P. J., Heland J., Holzinger R., Korrmann R., Lawrence M. G., Levin Z., Markowicz K. M., Mihalopoulos N., Minikin A., Ramanathan V., De Reus M., Roelofs G. J., … Ziereis H. (2002). Global air pollution crossroads over the Mediterranean. *Science*, *298*(5594). doi: 10.1126/science.1075457

Lelieveld J., Proestos Y., Hadjinicolaou P., Tanarhte M., Tyrlis E., and Zittis G. (2016). Strongly increasing heat extremes in the Middle East and North Africa (MENA) in the 21st century. *Climatic Change*, *137*(1–2), 245–260. doi: 10.1007/s10584-016-1665-6

Li W. C. (2014). Occurrence, sources, and fate of pharmaceuticals in aquatic environment and soil. *Environmental Pollution*, *187*, 193–201. doi: 10.1016/j.envpol.2014.01.015

Liaropoulos A., Sapountzaki K., and Nivolianitou Z. (2019). Adopting risk governance in the offshore oil industry and in diverse cultural and geopolitical context: North Sea vs Eastern Mediterranean countries. *Safety Science*, *120*, 471–483. doi: 10.1016/j.ssci.2019.07.032

Ligorini V., Malet N., Garrido M., Derolez V., Amand M., Bec B., Cecchi P., and Pasqualini V. (2022). Phytoplankton dynamics and bloom events in oligotrophic Mediterranean lagoons: seasonal patterns but hazardous trends. *Hydrobiologia*, *849*(10), 2353–2375. doi: 10.1007/s10750-022-04874-0

Lionello P., Barriopedro D., Ferrarin C., Nicholls R. J., Orlić M., Raicich F., Reale M., Umgiesser G., Vousdoukas M., and Zanchettin D. (2021). Extreme floods of Venice: characteristics, dynamics, past and future evolution (review article). *Natural Hazards and Earth System Sciences*, *21*(8), 2705–2731. doi: 10.5194/nhess-21-2705-2021

Lionello P., Conte D., Marzo L., and Scarascia L. (2017). The contrasting effect of increasing mean sea level and decreasing storminess on the maximum water level during storms along the coast of the Mediterranean Sea in the mid 21st century. *Global and Planetary Change*, *151*, 80–91. doi: 10.1016/j.gloplacha.2016.06.012

Lionello P., Conte D., and Reale M. (2019). The effect of cyclones crossing the Mediterranean region on sea level anomalies on the Mediterranean Sea coast. *Natural Hazards and Earth System Sciences*, *19*(7), 1541–1564. doi: 10.5194/nhess-19-1541-2019

Lionello P., and Scarascia L. (2018). The relation between climate change in the Mediterranean region and global warming. *Regional Environmental Change*, *18*(5), 1481–1493. doi: 10.1007/s10113-018-1290-1

Lionello P., and Scarascia L. (2020). The relation of climate extremes with global warming in the Mediterranean region and its north versus south contrast. *Regional Environmental Change*, *20*(1), 31. doi: 10.1007/s10113-020-01610-z

Lipizer M., Berto D., Cermelj B., Fafandjel M., Formalewicz M., Hatzianestis I., Ilijanić N., Kaberi H., Kralj M., Matijevic S., Molina Jack M. E., Parinos C., Tronczynski J., and Giani M. (2022). Trace metals and polycyclic aromatic hydrocarbons in the Eastern Mediterranean sediments: Concentration ranges as a tool for quality control of large data collections. *Marine Pollution Bulletin*, *185*. doi: 10.1016/j.marpolbul.2022.114181

Lira-Loarca A., and Besio G. (2022). Future changes and seasonal variability of the directional wave spectra in the Mediterranean Sea for the 21st century. *Environmental Research Letters*, *17*(10), 104015. doi: 10.1088/1748-9326/ac8ec4

Liubartseva S., Coppini G., Lecci R., and Clementi E. (2018). Tracking plastics in the Mediterranean: 2D Lagrangian model. *Marine Pollution Bulletin*, *129*(1). doi: 10.1016/j.marpolbul.2018.02.019

López-Olmedilla L., Almeida L. P., de Figueiredo S. A., Fontán-Bouzas Á., Silva P. A., and Alcántara-Carrió J. (2022). Effect of alongshore sediment supply gradients on projected shoreline position under sea-level rise (northwestern Portuguese coast). *Estuarine, Coastal and Shelf Science*, *271*, 107876. doi: 10.1016/j.ecss.2022.107876

Loupasakis C. (2020). An overview of the land subsidence phenomena occurring in Greece, triggered by the overexploitation of the aquifers for irrigation and mining purposes. *Proceedings of the International Association of Hydrological Sciences*, *382*, 321–326. doi: 10.5194/piahs-382-321-2020

Ludwig W., Bouwman A. F., Dumont E., and Lespinas F. (2010). Water and nutrient fluxes from major Mediterranean and Black Sea rivers: Past and future trends and their implications for the basin-scale budgets. *Global Biogeochemical Cycles*, *24*(4). doi: 10.1029/2009gb003594

Lutz S. R., Mallucci S., Diamantini E., Majone B., Bellin A., and Merz R. (2016). Hydroclimatic and water quality trends across three Mediterranean river basins. *Science of The Total Environment*, *571*, 1392–1406. doi: 10.1016/j.scitotenv.2016.07.102

Maccioni A., Canopoli L., Cubeddu V., Cucca E., Dessena S., Morittu S., Filigheddu R., Padedda B. M., and Farris E. (2021). Gradients of salinity and plant community richness and diversity in two different Mediterranean coastal ecosystems in NW Sardinia. *Biodiversity Data Journal*, *9*, e71247. doi: 10.3897/bdj.9.e71247

Makris C. V., Tolika K., Baltikas V. N., Velikou K., and Krestenitis Y. N. (2023). The impact of climate change on the storm surges of the Mediterranean Sea: Coastal sea level responses to deep depression atmospheric systems. *Ocean Modelling*, *181*, 102149. doi: 10.1016/j.ocemod.2022.102149

Malagó A., Bouraoui F., Grizzetti B., and De Roo A. (2019). Modelling nutrient fluxes into the Mediterranean Sea. *Journal of Hydrology: Regional Studies*, *22*, 100592. doi: 10.1016/j.ejrh.2019.01.004

Mandour A., El-Sayed M. K., El-Gamal A. A., Khadr A. M., and Elshazly A. (2021). Temporal distribution of trace metals pollution load index in the Nile Delta coastal surface sediments. *Marine Pollution Bulletin*, *167*. doi: 10.1016/j.marpolbul.2021.112290

Mannino A. M., Balistreri P., and Deidun A. (2017). The Marine Biodiversity of the Mediterranean Sea in a Changing Climate: The Impact of Biological Invasions. In *Mediterranean Identities - Environment, Society, Culture*. InTech. doi: 10.5772/intechopen.69214

Marchane A., Tramblay Y., Hanich L., Ruelland D., and Jarlan L. (2017). Climate change impacts on surface water resources in the Rheraya catchment (High Atlas, Morocco). *Hydrological Sciences Journal*, *62*(6), 979–995. doi: 10.1080/02626667.2017.1283042

Marcos M., Tsimplis M. N., and Shaw A. G. P. (2009). Sea level extremes in southern Europe. *Journal of Geophysical Research*, *114*(C1), C01007. doi: 10.1029/2008jc004912

Marcos M., and Woodworth P. L. (2017). Spatiotemporal changes in extreme sea levels along the coasts of the North Atlantic and the Gulf of Mexico. *Journal of Geophysical Research: Oceans*, *122*(9), 7031–7048. doi: 10.1002/2017jc013065

Mariotti A., Pan Y., Zeng N., and Alessandri A. (2015). Long-term climate change in the Mediterranean region in the midst of decadal variability. *Climate Dynamics*, *44*, 1437–1456. doi: 10.1007/s00382-015-2487-3

Marriner N., Morhange C., Flaux C., and Carayon N. (2017). Harbors and Ports, Ancient. In A. S. Gilbert (Ed.), *Encyclopedia of Geoarchaeology* (pp. 382–403). Springer Netherlands. doi: 10.1007/978-1-4020-4409-0_119

Marsili L., Jiménez B., and Borrell A. (2018). Persistent Organic Pollutants in Cetaceans Living in a Hotspot Area: The Mediterranean Sea. In *Marine Mammal Ecotoxicology: Impacts of Multiple Stressors on Population Health*. doi: 10.1016/b978-0-12-812144-3.00007-3

Marx A., Kumar R., Thober S., Rakovec O., Wanders N., Zink M., Wood E. F., Pan M., Sheffield J., and Samaniego L. (2018). Climate change alters low flows in Europe under global warming of 1.5, 2, and 3 °C. *Hydrology and Earth System Sciences*, *22*(2), 1017–1032. doi: 10.5194/hess-22-1017-2018

MedECC (2020). *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report* (W. Cramer, J. Guiot, & K. Marini, Eds.). Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, 632 pp. doi: 10.5281/zenodo.4768833

Menendez M., García-Díez M., Fita L., Fernández J., Méndez F. J., and Gutiérrez J. M. (2014). High-resolution sea wind hindcasts over the Mediterranean area. *Climate Dynamics*, *42*(7–8), 1857–1872. doi: 10.1007/s00382-013-1912-8

Menéndez M., and Woodworth P. L. (2010). Changes in extreme high water levels based on a quasi-global tide-gauge data set. *Journal of Geophysical Research: Oceans*, *115*(C10), 2009JC005997. doi: 10.1029/2009jc005997

Merhaby D., Rabodonirina S., Net S., Ouddane B., and Halwani J. (2019). Overview of sediments pollution by PAHs and PCBs in mediterranean basin: Transport, fate, occurrence, and distribution. *Marine Pollution Bulletin*, *149*. doi: 10.1016/j.marpolbul.2019.110646

Miglietta. (2019). Mediterranean Tropical-Like Cyclones (Medicanes). *Atmosphere*, *10*(4), 206. doi: 10.3390/atmos10040206

Milano M., Ruelland D., Fernandez S., Dezetter A., Fabre J., Servat E., Fritsch J.-M., Ardoin-Bardin S., and Thivet G. (2013). Current state of Mediterranean water resources and future trends under climatic and anthropogenic changes. *Hydrological Sciences Journal*, *58*(3), 498–518. doi: 10.1080/02626667.2013.774458

Miralles D. G., Van Den Berg M. J., Gash J. H., Parinussa R. M., De Jeu R. A. M., Beck H. E., Holmes T. R. H., Jiménez C., Verhoest N. E. C., Dorigo W. A., Teuling A. J., and Johannes Dolman A. (2014). El Niño–La Niña cycle and recent trends in continental evaporation. *Nature Climate Change*, *4*(2), 122–126. doi: 10.1038/nclimate2068

Moemken J., Reyers M., Feldmann H., and Pinto J. G. (2018). Future Changes of Wind Speed and Wind Energy Potentials in EURO-CORDEX Ensemble Simulations. *Journal of Geophysical Research: Atmospheres*, *123*(12), 6373–6389. doi: 10.1029/2018jd028473

Molinero J. C., Casini M., and Buecher E. (2008). The influence of the Atlantic and regional climate variability on the long-term changes in gelatinous carnivore populations in the northwestern Mediterranean. *Limnology and Oceanography*, *53*(4), 1456–1467. doi: 10.4319/lo.2008.53.4.1456

Molinié G., Déqué M., Coppola E., Blanchet J., and Neppel L. (2016). Sub-chapter 1.3.1. Heavy precipitation in the Mediterranean basin. In *The Mediterranean region under climate change* (pp. 107–114). IRD Éditions. doi: 10.4000/books.irdeditions.23121

Molnar J. L., Gamboa R. L., Revenga C., and Spalding M. D. (2008). Assessing the global threat of invasive species to marine biodiversity. *Frontiers in Ecology and the Environment*, *6*(9), 485–492. doi: 10.1890/070064

Monserrat S., Ibbetson A., and Thorpe A. (1991). Atmospheric gravity waves and the "Rissaga" phenomenon. *Quarterly Journal of the Royal Meteorological Society*, *117*(499), 553–570. doi: 10.1002/qj.49711749907

Monserrat S., Vilibić I., and Rabinovich A. B. (2006). Meteotsunamis: atmospherically induced destructive ocean waves in the tsunami frequency band. *Natural Hazards and Earth System Sciences*, *6*(6), 1035–1051. doi: 10.5194/nhess-6-1035-2006

Moore C. M., Mills M. M., Arrigo K. R., Berman-Frank I., Bopp L., Boyd P. W., Galbraith E. D., Geider R. J., Guieu C., Jaccard S. L., Jickells T. D., La Roche J., Lenton T. M., Mahowald N. M., Marañón E., Marinov I., Moore J. K., Nakatsuka T., Oschlies A., … Ulloa O. (2013). Processes and patterns of oceanic nutrient limitation. *Nature Geoscience*, *6*(9), 701–710. doi: 10.1038/ngeo1765

Morabito E., Radaelli M., Corami F., Turetta C., Toscano G., and Capodaglio G. (2018). Temporal evolution of cadmium, copper and lead concentration in the Venice Lagoon water in relation with the speciation and dissolved/particulate partition. *Marine Pollution Bulletin*, *129*(2). doi: 10.1016/j.marpolbul.2017.10.043

Morsy K. M., Mishra A. K., and Galal M. M. (2020). Water Quality Assessment of the Nile Delta Lagoons. *Air, Soil and Water Research*, *13*. doi: 10.1177/1178622120963072

Mourtzas N., Kolaiti E., and Anzidei M. (2015). Vertical land movements and sea level changes along the coast of Crete (Greece) since Late Holocene. *Quaternary International*, 1–28. doi: 10.1016/j.quaint.2015.08.008

Naidja L., Ali-Khodja H., and Khardi S. (2018). Sources and levels of particulate matter in North African and Sub-Saharan cities: a literature review. *Environmental Science and Pollution Research*, *25*(13). doi: 10.1007/s11356-018-1715-x

Navarro-Pedreño J., Gómez Lucas I., Almendro-Candel M., and Melendez-Pastor I. (2008). Heavy metals in Mediterranean soils. *Soil Contamination Research Trends* (pp.161-176). Nova Science Publishers Inc. https://www.researchgate.net/publication/235935560_Heavy_metals_in_Mediterranean_soils

Neumann B., Vafeidis A. T., Zimmermann J., and Nicholls R. J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding - A global assessment. *PLoS ONE*, *10*(3). doi: 10.1371/journal.pone.0118571

Nicholls R. J., Lincke D., Hinkel J., Brown S., Vafeidis A. T., Meyssignac B., Hanson S. E., Merkens J.-L., and Fang J. (2021). A global analysis of subsidence, relative sea-level change and coastal flood exposure. *Nature Climate Change*, *11*(4), 338–342. doi: 10.1038/s41558-021-00993-z

Obermann-Hellhund A., Conte D., Somot S., Torma C. Z., and Ahrens B. (2018). Mistral and Tramontane wind systems in climate simulations from 1950 to 2100. *Climate Dynamics*, *50*(1–2), 693–703. doi: 10.1007/s00382-017-3635-8

Occhipinti-Ambrogi A., and Galil B. (2010). Marine alien species as an aspect of global change. *Advances in Oceanography and Limnology*, *1*(1), 199–218. doi: 10.1080/19475721003743876

Oliver E. C. J., Donat M. G., Burrows M. T., Moore P. J., Smale D. A., Alexander L. V, Benthuysen J. A., Feng M., Sen Gupta A., Hobday A. J., Holbrook N. J., Perkins-Kirkpatrick S. E., Scannell H. A., Straub S. C., and Wernberg T. (2018). Longer and more frequent marine heatwaves over the past century. *Nature Communications*, *9*(1), 1324. doi: 10.1038/s41467-018-03732-9

Oppenheimer M., Glavovic B.C., Hinkel J., van de Wal R., Magnan A.K., Abd-Elgawad A., Cai R., Cifuentes-Jara M., DeConto R.M., Ghosh T., Hay J., Isla F., Marzeion B., Meyssignac B., and Sebesvari Z. (2019). Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N. M. Weyer (Eds.), *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 321–445. doi: 10.1017/9781009157964.006

Ouda M., Kadadou D., Swaidan B., Al-Othman A., Al-Asheh S., Banat F., and Hasan S. W. (2021). Emerging contaminants in the water bodies of the Middle East and North Africa (MENA): A critical review. *Science of the Total Environment*, *754*. doi: 10.1016/j.scitotenv.2020.142177

Pagán J. I., López M., López I., Tenza-Abril A. J., and Aragonés L. (2018). Causes of the different behaviour of the shoreline on beaches with similar characteristics. Study case of the San Juan and Guardamar del Segura beaches, Spain. *Science of The Total Environment*, *634*, 739–748. doi: 10.1016/j.scitotenv.2018.04.037

Paiano A., Crovella T., and Lagioia G. (2020). Managing sustainable practices in cruise tourism: the assessment of carbon footprint and waste of water and beverage packaging. *Tourism Management*, *77*, 104016. doi: 10.1016/j.tourman.2019.104016

Palmiéri J., Orr J. C., Dutay J.-C., Béranger K., Schneider A., Beuvier J., and Somot S. (2015). Simulated anthropogenic CO_2 storage and acidification of the Mediterranean Sea. *Biogeosciences*, *12*(3), 781–802. doi: 10.5194/bg-12-781-2015

Papazachos B. C., Koutitas Ch., Hatzidimitriou P. M., Karacostas B. G., and Papaioannou Ch. A. (1985). Source and short-distance propagation of the July 9, 1956 southern Aegean tsunami. *Marine Geology*, *65*(3–4), 343–351. doi: 10.1016/0025-3227(85)90064-7

Pastor F., Valiente J. A., and Khodayar S. (2020). A Warming Mediterranean: 38 Years of Increasing Sea Surface Temperature. *Remote Sensing*, *12*(17), 2687. doi: 10.3390/rs12172687

Patlakas P., Stathopoulos C., Tsalis C., and Kallos G. (2021). Wind and wave extremes associated with tropical-like cyclones in the Mediterranean basin. *International Journal of Climatology*, *41*(S1). doi: 10.1002/joc.6795

Pedrotti M. L., Lombard F., Baudena A., Galgani F., Elineau A., Petit S., Henry M., Troublé R., Reverdin G., Ser-Giacomi E., Kedzierski M., Boss E., and Gorsky G. (2022). An integrative assessment of the plastic debris load in the Mediterranean Sea. *Science of The Total Environment*, *838*, 155958. doi: 10.1016/j.scitotenv.2022.155958

Peña-Angulo D., Vicente-Serrano S. M., Domínguez-Castro F., Murphy C., Reig F., Tramblay Y., Trigo R. M., Luna M. Y., Turco M., Noguera I., Aznárez-Balta M., García-Herrera R., Tomas-Burguera M., and El Kenawy A. (2020). Long-term precipitation in Southwestern Europe reveals no clear trend attributable to anthropogenic forcing. *Environmental Research Letters*, *15*(9), 094070. doi: 10.1088/1748-9326/ab9c4f

Perennou C., Gaget E., Galewski T., Geijzendorffer I., and Guelmami A. (2020). Evolution of wetlands in Mediterranean region. In *Water Resources in the Mediterranean Region*. doi: 10.1016/b978-0-12-818086-0.00011-x

Pérez Gómez B., Vilibić I., Šepić J., Međugorac I., Ličer M., Testut L., Fraboul C., Marcos M., Abdellaoui H., Álvarez Fanjul E., Barbalić D., Casas B., Castaño-Tierno A., Čupić S., Drago A., Fraile M. A., Galliano D. A., Gauci A., Gloginja B., … Zodiatis G. (2022). Coastal sea level monitoring in the Mediterranean and Black seas. *Ocean Science*, *18*(4), 997–1053. doi: 10.5194/os-18-997-2022

Perrings C., Williamson M., Barbier E. B., Delfino D., Dalmazzone S., Shogren J., Simmons P., and Watkinson A. (2002). Biological invasion risks and the public good: An economic perspective. *Ecology and Society*, *6*(1). doi: 10.5751/es-00396-060101

Perrone M. R., Paladini F., Becagli S., Amore A., and Romano S. (2022). Daytime and nighttime chemical and optical properties of fine and coarse particles at a central Mediterranean coastal site. *Environmental Science and Pollution Research*, *29*(28). doi: 10.1007/s11356-021-18173-z

Piante C., Ody D.,2015. Blue Growth in the Mediterranean Sea: the Challenge of Good Environmental Status. *MedTrends Project*. WWF-France. 192 pages.

Pisano A., Marullo S., Artale V., Falcini F., Yang C., Leonelli F. E., Santoleri R., and Buongiorno Nardelli B. (2020). New Evidence of Mediterranean Climate Change and Variability from Sea Surface Temperature Observations. *Remote Sensing*, *12*(1), 132. doi: 10.3390/rs12010132

Pistocchi A., Bleninger T., Breyer C., Caldera U., Dorati C., Ganora D., Millán M. M., Paton C., Poullis D., Herrero F. S., Sapiano M., Semiat R., Sommariva C., Yuece S., and Zaragoza G. (2020a). Can seawater desalination be a win-win fix to our water cycle? *Water Research*, *182*, 115906. doi: 10.1016/j.watres.2020.115906

Pistocchi A., Bleninger T., and Dorati C. (2020b). Screening the hurdles to sea disposal of desalination brine around the Mediterranean. *Desalination*, *491*, 114570. doi: 10.1016/j.desal.2020.114570

Plan Bleu (2022). *State of Play of Tourism in the Mediterranean*. Interreg Med Sustainable Tourism Community project. https://planbleu.org/en/publications/state-of-play-of-tourism-in-the-mediterranean/

Planton S., Lionello P., Artale V., Aznar R., Carrillo A., Colin J., Congedi L., Dubois C., Elizalde A., Gualdi S., Hertig E., Jacobeit J., Jordà G., Li L., Mariotti A., Piani C., Ruti P., Sanchez-Gomez E., Sannino G., … Tsimplis M. (2012). The Climate of the Mediterranean Region in Future Climate Projections. In *The Climate of the Mediterranean Region* (pp. 449–502). Elsevier. doi: 10.1016/B978-0-12-416042-2.00008-2

Polinov S., Bookman R., and Levin N. (2021). Spatial and temporal assessment of oil spills in the Mediterranean Sea. *Marine Pollution Bulletin*, *167*. doi: 10.1016/j.marpolbul.2021.112338

Poulos S. E., and Collins M. B. (2002). Fluviatile sediment fluxes to the Mediterranean Sea: a quantitative approach and the influence of dams. *Geological Society, London, Special Publications*, *191*(1), 227–245. doi: 10.1144/gsl.sp.2002.191.01.16

Powley H. R., Dürr H. H., Lima A. T., Krom M. D., and Van Cappellen P. (2016). Direct Discharges of Domestic Wastewater are a Major Source of Phosphorus and Nitrogen to the Mediterranean Sea. *Environmental Science and Technology*, *50*(16), 8722–8730. doi: 10.1021/acs.est.6b01742

Powley H. R., Krom M. D., and Van Cappellen P. (2018). Phosphorus and nitrogen trajectories in the Mediterranean Sea (1950–2030): Diagnosing basin-wide anthropogenic nutrient enrichment. *Progress in Oceanography*, *162*, 257–270. doi: 10.1016/j.pocean.2018.03.003

Pujo-Pay M., Conan P., Oriol L., Cornet-Barthaux V., Falco C., Ghiglione J. F., Goyet C., Moutin T., and Prieur L. (2011). Integrated survey of elemental stoichiometry (C, N, P) from the western to eastern Mediterranean Sea. *Biogeosciences*, *8*(4). doi: 10.5194/bg-8-883-2011

Purcell J.E. (2012). Jellyfish and Ctenophore Blooms Coincide with Human Proliferations and Environmental Perturbations. *Annual Review of Marine Science*, *4*(1), 209–235. doi: 10.1146/annurev-marine-120709-142751

Purcell J.E., Uye S., and Lo W. (2007). Anthropogenic causes of jellyfish blooms and their direct consequences for humans: a review. *Marine Ecology Progress Series*, *350*, 153–174. doi: 10.3354/meps07093

Quignard, J.-P., & Tomasini, J. A. (2007). Mediterranean fish biodiversity. *Biologia Marina Mediterranea*, *7*(3), 1–66. http://publikationen.ub.uni-frankfurt.de/frontdoor/index/index/docId/16126

Ramis C., and Jansà A. (1983). Condiciones meteorológicas simultáneas a la aparición de oscilaciones del nivel del mar de amplitud extraordinaria en el Mediterráneo occidental. *Revista de Geofísica*, *39*, 35–42.

Re V., and Zuppi G. M. (2011). Influence of precipitation and deep saline groundwater on the hydrological systems of Mediterranean coastal plains: a general overview. *Hydrological Sciences Journal*, *56*(6), 966–980. doi: 10.1080/02626667.2011.597355

Reale M., Cabos Narvaez W. D., Cavicchia L., Conte D., Coppola E., Flaounas E., Giorgi F., Gualdi S., Hochman A., Li L., Lionello P., Podrascanin Z., Salon S., Sanchez-Gomez E., Scoccimarro E., Sein D. V, and Somot S. (2022a). Future projections of Mediterranean cyclone characteristics using the Med-CORDEX ensemble of coupled regional climate system models. *Climate Dynamics*, *58*(9–10), 2501–2524. doi: 10.1007/s00382-021-06018-x

Reale M., Cossarini G., Lazzari P., Lovato T., Bolzon G., Masina S., Solidoro C., and Salon S. (2022b). Acidification, deoxygenation, nutrient and biomasses decline in a warming Mediterranean Sea. *Biogeosciences*, *19*, 4035–4065. doi: 10.5194/bg-19-4035-2022

Reimann L., Jones B., Nikoletopoulos T., and Vafeidis A. T. (2021). Accounting for internal migration in spatial population projections - A gravity-based modeling approach using the Shared Socioeconomic Pathways. *Environmental Research Letters*, *16*(7). doi: 10.1088/1748-9326/ac0b66

Reimann L., Merkens J. L., and Vafeidis A. T. (2018). Regionalized Shared Socioeconomic Pathways: narratives and spatial population projections for the Mediterranean coastal zone. *Regional Environmental Change*, *18*(1). doi: 10.1007/s10113-017-1189-2

Rivetti I., Boero F., Fraschetti S., Zambianchi E., and Lionello P. (2017). Anomalies of the upper water column in the Mediterranean Sea. *Global and Planetary Change*, *151*, 68–79. doi: 10.1016/j.gloplacha.2016.03.001

Roccati A., Paliaga G., Luino F., Faccini F., and Turconi L. (2020). Rainfall Threshold for Shallow Landslides Initiation and Analysis of Long-Term Rainfall Trends in a Mediterranean Area. *Atmosphere*, *11*(12), 1367. doi: 10.3390/atmos11121367

Rodellas V., Garcia-Orellana J., Masqué P., Feldman M., Weinstein Y., and Boyle E. A. (2015). Submarine groundwater discharge as a major source of nutrients to the Mediterranean Sea. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(13), 3926–3930. doi: 10.1073/pnas.1419049112

Rodriguez M., Maleuvre C., Jollivet-Castelot M., d'Acremont E., Rabaute A., Lafosse M., Ercilla G., Vázquez J. T., Alonso B., Ammar A., and Gorini C. (2017). Tsunamigenic submarine landslides along the Xauen–Tofiño banks in the Alboran Sea (Western Mediterranean Sea). *Geophysical Journal International*, *209*(1), 266–281. doi: 10.1093/gji/ggx028

Romera R., Gaertner M. Á., Sánchez E., Domínguez M., González-Alemán J. J., and Miglietta M. M. (2017). Climate change projections of medicanes with a large multi-model ensemble of regional climate models. *Global and Planetary Change*, *151*, 134–143. doi: 10.1016/j.gloplacha.2016.10.008

Romero E., Garnier J., Lassaletta L., Billen G., Gendre R. Le, Riou P., and Cugier P. (2013). Large-scale patterns of river inputs in southwestern Europe: Seasonal and interannual variations and potential eutrophication effects at the coastal zone. *Biogeochemistry*, *113*(1–3). doi: 10.1007/s10533-012-9778-0

Romero E., Ludwig W., Sadaoui M., Lassaletta L., Bouwman A. F., Beusen A. H. W., Apeldoorn D. van, Sardans J., Janssens I. A., Ciais P., Obersteiner M., and Peñuelas J. (2021). The Mediterranean Region as a Paradigm of the Global Decoupling of N and P Between Soils and Freshwaters. *Global Biogeochemical Cycles*, *35*(3). doi: 10.1029/2020gb006874

Romero R., and Emanuel K. (2013). Medicane risk in a changing climate. *Journal of Geophysical Research: Atmospheres*, *118*(12), 5992–6001. doi: 10.1002/jgrd.50475

Romero-Freire A., Santos-Echeandía J., Neira P., and Cobelo-García A. (2019). Less-studied technology-critical elements (Nb, ta, ga, in, ge, te) in the marine environment: Review on their concentrations in water and organisms. *Frontiers in Marine Science*, 6:532. doi: 10.3389/fmars.2019.00532

Rovere A., Stocchi P., and Vacchi M. (2016). Eustatic and Relative Sea Level Changes. *Current Climate Change Reports*, *2*(4), 221–231. doi: 10.1007/s40641-016-0045-7

Ruffault J., Curt T., Moron V., Trigo R. M., Mouillot F., Koutsias N., Pimont F., Martin-StPaul N., Barbero R., Dupuy J. L., Russo A., and Belhadj-Khedher C. (2020). Increased likelihood of heat-induced large wildfires in the Mediterranean Basin. *Scientific Reports*, *10*(1). doi: 10.1038/s41598-020-70069-z

Ruosteenoja K., Markkanen T., Venäläinen A., Räisänen P., and Peltola H. (2018). Seasonal soil moisture and drought occurrence in Europe in CMIP5 projections for the 21st century. *Climate Dynamics*, *50*(3–4), 1177–1192. doi: 10.1007/s00382-017-3671-4

Hamza H., Beya M. A., Bain A., de Wit R., and Klein J. (2022). First record of the invasive Asian date mussel Arcuatula senhousia (Benson, 1842) in El Mellah Lagoon (Southern coast of Algerian Basin, Western Mediterranean). *Bioinvasions Records*, *11*(3), 686–699. doi: 10.3391/bir.2022.11.3.05

Saleh M., and Becker M. (2019). New estimation of Nile Delta subsidence rates from InSAR and GPS analysis. *Environmental Earth Sciences*, *78*(1), 6. doi: 10.1007/s12665-018-8001-6

Sanchez-Gomez E., Somot S., and Mariotti A. (2009). Future changes in the Mediterranean water budget projected by an ensemble of regional climate models. *Geophysical Research Letters*, *36*(21), L21401. doi: 10.1029/2009gl040120

Santos I. R., Chen X., Lecher A. L., Sawyer A. H., Moosdorf N., Rodellas V., Tamborski J., Cho H. M., Dimova N., Sugimoto R., Bonaglia S., Li H., Hajati M. C., and Li L. (2021). Submarine groundwater discharge impacts on coastal nutrient biogeochemistry. *Nature Reviews Earth & Environment 2021 2:5*, *2*(5), 307–323. doi: 10.1038/s43017-021-00152-0

Santos-Echeandía J., Campillo J. A., Egea J. A., Guitart C., González C. J., Martínez-Gómez C., León V. M., Rodríguez-Puente C., and Benedicto J. (2021). The influence of natural vs anthropogenic factors on trace metal(loid) levels in the Mussel Watch programme: Two decades of monitoring in the Spanish Mediterranean sea. *Marine Environmental Research*, *169*. doi: 10.1016/j.marenvres.2021.105382

Scarselli N. (2020). Submarine landslides – architecture, controlling factors and environments. A summary. *Regional Geology and Tectonics: Volume 1: Principles of Geologic Analysis*, 417–439. doi: 10.1016/b978-0-444-64134-2.00015-8

Schiaparelli S., Castellano M., Povero P., Sartoni G., and Cattaneo-Vietti R. (2007). A benthic mucilage event in North-Western Mediterranean Sea and its possible relationships with the summer 2003 European heatwave: Short term effects on littoral rocky assemblages. *Marine Ecology*, *28*(3), 341-353. doi: 10.1111/j.1439-0485.2007.00155.x

Schroeder K., Chiggiato J., Bryden H. L., Borghini M., and Ben Ismail S. (2016). Abrupt climate shift in the Western Mediterranean Sea. *Scientific Reports*, *6*(1), 23009. doi: 10.1038/srep23009

Scicchitano G., Scardino G., Monaco C., Piscitelli A., Milella M., De Giosa F., and Mastronuzzi G. (2021). Comparing impact effects of common storms and Medicanes along the coast of south-eastern Sicily. *Marine Geology*, *439*, 106556. doi: 10.1016/j.margeo.2021.106556

Seebens H., Blackburn T. M., Dyer E. E., Genovesi P., Hulme P. E., Jeschke J. M., Pagad S., Pyšek P., Winter M., Arianoutsou M., Bacher S., Blasius B., Brundu G., Capinha C., Celesti-Grapow L., Dawson W., Dullinger S., Fuentes N., Jäger H., … Essl F. (2017). No saturation in the accumulation of alien species worldwide. *Nature Communications*, *8*(1), 14435. doi: 10.1038/ncomms14435

Seneviratne S. I., Zhang X., Adnan M., Badi W., Dereczynski C., Di Luca A., Ghosh S., Iskandar I., Kossin J., Lewis S., Otto F., Pinto I., Satoh M., Vicente-Serrano S. M., Wehner M., and Zhou B. (2021). Weather and Climate Extreme Events in a Changing Climate. In Masson-Delmotte V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1513–1766). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. doi: 10.1017/9781009157896.013

Seto K. C., Fragkias M., Güneralp B., and Reilly M. K. (2011). A meta-analysis of global urban land expansion. *PLoS ONE*, *6*(8) : e23777. doi: 10.1371/journal.pone.0023777

Sevault F., Somot S., Alias A., Dubois C., Lebeaupin-Brossier C., Nabat P., Adloff F., Déqué M., Decharme B., and Dé Qué M. (2014). A fully coupled Mediterranean regional climate system model: design and evaluation of the ocean component for the 1980–2012 period. *Tellus A: Dynamic Meteorology and Oceanography*, *66*(1), 23967. doi: 10.3402/tellusa.v66.23967

Shaw B., Ambraseys N. N., England P. C., Floyd M. A., Gorman G. J., Higham T. F. G., Jackson J. A., Nocquet J.-M., Pain C. C., and Piggott M. D. (2008). Eastern Mediterranean tectonics and tsunami hazard inferred from the AD 365 earthquake. *Nature Geoscience*, *1*(4), 268–276. doi: 10.1038/ngeo151

Simberloff D., Martin J.-L., Genovesi P., Maris V., Wardle D. A., Aronson J., Courchamp F., Galil B., García-Berthou E., Pascal M., Pyšek P., Sousa R., Tabacchi E., and Vilà M. (2013). Impacts of biological invasions: what's what and the way forward. *Trends in Ecology & Evolution*, *28*(1), 58–66. doi: 10.1016/j.tree.2012.07.013

Siokou-Frangou I., Christaki U., Mazzocchi M. G., Montresor M., Ribera D'Alcala M., Vaque D., and Zingone A. (2010). Plankton in the open mediterranean Sea: A review. *Biogeosciences*, *7*(5), 1543–1586. doi: 10.5194/bg-7-1543-2010

Skliris N., Zika J. D., Herold L., Josey S. A., and Marsh R. (2018). Mediterranean sea water budget long-term trend inferred from salinity observations. *Climate Dynamics*, *51*(7–8), 2857–2876. doi: 10.1007/s00382-017-4053-7

Solidoro C., Cossarini G., Lazzari P., Galli G., Bolzon G., Somot S., and Salon S. (2022). Modeling Carbon Budgets and Acidification in the Mediterranean Sea Ecosystem Under Contemporary and Future Climate. *Frontiers in Marine Science*, *8*. doi: 10.3389/fmars.2021.781522

Soloviev S. L., Solovieva O. N., Go C. N., Kim K. S., Shchetnikov N. A., Bonnin J., Levin B. W., Tinti S., and Papadopoulos G. A. (2000). Main Tsunamigenic Zones in the Mediterranean Sea. In J. Bonnin, B. W. Levin, S. Tinti, & G. A. Papadopoulos (Eds.), *Tsunamis in the Mediterranean Sea 2000 B.C.–2000 A.D.* (Vol. 13, pp. 1–15). Springer Netherlands. doi: 10.1007/978-94-015-9510-0_1

Sørensen M. B., Spada M., Babeyko A., Wiemer S., and Grünthal G. (2012). Probabilistic tsunami hazard in the Mediterranean Sea. *Journal of Geophysical Research: Solid Earth*, *117*(B1), 1305. doi:10.1029/2010jb008169

Sorte S., Rodrigues V., Borrego C., and Monteiro A. (2020). Impact of harbour activities on local air quality: A review. *Environmental Pollution*, *257*. doi: 10.1016/j.envpol.2019.113542

Soto-Navarro J., Jordá G., Amores A., Cabos W., Somot S., Sevault F., Macías D., Djurdjevic V., Sannino G., Li L., and Sein D. (2020). Evolution of Mediterranean Sea water properties under climate change scenarios in the Med-CORDEX ensemble. *Climate Dynamics*, *54*(3–4), 2135–2165. doi: 10.1007/s00382-019-05105-4

Spada G., and Melini D. (2022). New estimates of ongoing sea level change and land movements caused by Glacial Isostatic Adjustment in the Mediterranean region. *Geophysical Journal International*, *229*(2), 984–998. doi: 10.1093/gji/ggab508

Spinoni J., Naumann G., and Vogt J. V. (2017). Pan-European seasonal trends and recent changes of drought frequency and severity. *Global and Planetary Change*, *148*, 113–130. doi: 10.1016/j.gloplacha.2016.11.013

Spinoni J., Vogt J., Naumann G., Carrao H., and Barbosa P. (2015). Towards identifying areas at climatological risk of desertification using the Köppen-Geiger classification and FAO aridity index. *International Journal of Climatology*, *35*(9), 2210–2222. doi: 10.1002/joc.4124

Spinoni J., Vogt J. V., Naumann G., Barbosa P., and Dosio A. (2018). Will drought events become more frequent and severe in Europe? *International Journal of Climatology*, *38*(4), 1718–1736. doi: 10.1002/joc.5291

Stagge J. H., Kingston D. G., Tallaksen L. M., and Hannah D. M. (2017). Observed drought indices show increasing divergence across Europe. *Scientific Reports*, *7*(1), 14045. doi: 10.1038/s41598-017-14283-2

Suárez-Almiñana S., Pedro-Monzonís M., Paredes-Arquiola J., Andreu J., and Solera A. (2017). Linking Pan-European data to the local scale for decision making for global change and water scarcity within water resources planning and management. *Science of The Total Environment*, *603–604*, 126–139. doi: 10.1016/j.scitotenv.2017.05.259

Suaria G., Avio C. G., Mineo A., Lattin G. L., Magaldi M. G., Belmonte G., Moore C. J., Regoli F., and Aliani S. (2016). The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters. *Scientific Reports*, *6*(1), 37551. doi: 10.1038/srep37551

Svigkas N., Papoutsis I., Constantinos L., Tsangaratos P., Kiratzi A., and Kontoes C. H. (2016). Land subsidence rebound detected via multi-temporal InSAR and ground truth data in Kalochori and Sindos regions, Northern Greece. *Engineering Geology*, *209*, 175–186. doi: 10.1016/j.enggeo.2016.05.017

Tavoloni T., Miniero R., Bacchiocchi S., Brambilla G., Ciriaci M., Griffoni F., Palombo P., Stecconi T., Stramenga A., and Piersanti A. (2021). Heavy metal spatial and temporal trends (2008–2018) in clams and mussel from Adriatic Sea (Italy): Possible definition of forecasting models. *Marine Pollution Bulletin*, *163*. doi: 10.1016/j.marpolbul.2020.111865

Teresita G., Nicola M., Luca F., and Pierfrancesco C. (2019). Tsunami risk perception along the Tyrrhenian coasts of Southern Italy: the case of Marsili volcano. *Natural Hazards*, *97*(1), 437–454. doi: 10.1007/s11069-019-03652-x

Theocharis A., Nittis K., Kontoyiannis H., Papageorgiou E., and Balopoulos E. (1999). Climatic changes in the Aegean Sea influence the eastern Mediterranean thermohaline circulation (1986-1997). *Geophysical Research Letters*, *26*(11), 1617–1620. doi: 10.1029/1999gl900320

Thober S., Kumar R., Wanders N., Marx A., Pan M., Rakovec O., Samaniego L., Sheffield J., Wood E. F., and Zink M. (2018). Multi-model ensemble projections of European river floods and high flows at 1.5, 2-, and 3-degrees global warming. *Environmental Research Letters*, *13*(1), 014003. doi: 10.1088/1748-9326/aa9e35

Tinti S., Maramai A., and Graziani L. (2001). A new version of the European tsunami catalogue: updating and revision. *Natural Hazards and Earth System Sciences*, *1*, 255–262. doi: 10.5194/nhess-1-255-2001

Tobin I., Vautard R., Balog I., Bréon F.-M., Jerez S., Ruti P. M., Thais F., Vrac M., and Yiou P. (2015). Assessing climate change impacts on European wind energy from ENSEMBLES high-resolution climate projections. *Climatic Change*, *128*(1–2), 99–112. doi: 10.1007/s10584-014-1291-0

Toledo I., Ignacio Pagán J., López I., Aragonés L., Ignacio Pag an J., opez I. L., Aragon es Ignacio Toledo L., and Aragon es L. (2022). Causes of the different behaviour against erosion: Study case of the Benidorm Beaches (1956-2021). *Marine Georesources & Geotechnology, 41*(6), 648–661. doi: 10.1080/1064119x.2022.2084003

Toomey T., Amores A., Marcos M., Orfila A., and Romero R. (2022). Coastal Hazards of Tropical-Like Cyclones Over the Mediterranean Sea. *Journal of Geophysical Research: Oceans*, *127*(2). doi: 10.1029/2021jc017964

Tosi L., Da Lio C., Teatini P., and Strozzi T. (2018). Land Subsidence in Coastal Environments: Knowledge Advance in the Venice Coastland by TerraSAR-X PSI. *Remote Sensing 2018, Vol. 10, Page 1191*, *10*(8), 1191. doi: 10.3390/rs10081191

Tosi L., Teatini P., and Strozzi T. (2013). Natural versus anthropogenic subsidence of Venice. *Scientific Reports*, *3*(1), 2710. doi: 10.1038/srep02710

Toth E., Bragalli C., and Neri M. (2018). Assessing the significance of tourism and climate on residential water demand: Panel-data analysis and non-linear modelling of monthly water consumptions. *Environmental Modelling and Software*, *103*., 52-51. doi: 10.1016/j.envsoft.2018.01.011

Touratier F., and Goyet C. (2011). Impact of the Eastern Mediterranean Transient on the distribution of anthropogenic CO2 and first estimate of acidification for the Mediterranean Sea. *Deep Sea Research Part I: Oceanographic Research Papers*, *58*(1), 1–15. doi: 10.1016/j.dsr.2010.10.002

Tous M., and Romero R. (2013). Meteorological environments associated with medicane development. *International Journal of Climatology*, *33*, 1–14. doi: 10.1002/joc.3428

Tovar-Sánchez A., Basterretxea G., Omar M. Ben, Jordi A., Sánchez-Quiles D., Makhani M., Mouna D., Muya C., and Anglès S. (2016). Nutrients, trace metals and B-vitamin composition of the Moulouya River: A major North African river discharging into the Mediterranean Sea. *Estuarine, Coastal and Shelf Science*, *176*, 47–57. doi: 10.1016/j.ecss.2016.04.006

Tramblay Y., Jarlan L., Hanich L., and Somot S. (2018). Future Scenarios of Surface Water Resources Availability in North African Dams. *Water Resources Management*, *32*(4), 1291–1306. doi:10.1007/s11269-017-1870-8

Transport and Environment (2019). One Corporation to Pollute Them All. Luxury cruise air emissions in Europe. 2019 European Federation for Transport and Environment AISBL. https://www.transportenvironment.org/articles/one-corporation-pollute-them-all

Treppiedi D., Cipolla G., Francipane A., and Noto L. V. (2021). Detecting precipitation trend using a multiscale approach based on quantile regression over a Mediterranean area. *International Journal of Climatology*, *41*(13), 5938–5955. doi: 10.1002/joc.7161

Trincardi F., Francocci F., Pellegrini C., Ribera d'Alcalà M., and Sprovieri M. (2023). The Mediterranean Sea in the Anthropocene. In *Oceanography of the Mediterranean Sea* (pp. 501–553). Elsevier. doi: 10.1016/b978-0-12-823692-5.00013-3

Tsikoti C., and Genitsaris S. (2021). Review of Harmful Algal Blooms in the Coastal Mediterranean Sea, with a Focus on Greek Waters. *Diversity*, *13*(8), 396. doi: 10.3390/d13080396

Ülker D., Burak S., Balas L., and Çağlar N. (2022). Mathematical modelling of oil spill weathering processes for contingency planning in Izmit Bay. *Regional Studies in Marine Science*, *50*. doi: 10.1016/j.rsma.2021.102155

Ulman A., Ferrario J., Forcada A., Seebens H., Arvanitidis C., Occhipinti-Ambrogi A., and Marchini A. (2019). Alien species spreading via biofouling on recreational vessels in the Mediterranean Sea. *Journal of Applied Ecology*, *56*(12), 2620–2629. doi: 10.1111/1365-2664.13502

UN (2021). The Second World Ocean Assessment: World Ocean Assessment II - Volume I & II. In *The Second World Ocean Assessment*. United Nations. doi: 10.18356/9789216040062

UNEP/MAP (2016). *Mediterranean Strategy for Sustainable Development 2016-2025*. Valbonne. Plan Bleu, Regional Activity Centre. https://wedocs.unep.org/bitstream/handle/20.500.11822/7097/mssd_2016_2025_eng.pdf

UNEP/MAP (2017). *Mediterranean Quality Status Report*. Athens. https://www.unep.org/unepmap/resources/quality-status-report-mediterranean-med-qsr-2017

UNEP/MAP, and Plan Bleu (2020). *State of the Environment and Development in the Mediterranean*. Nairobi. https://planbleu.org/wp-content/uploads/2021/04/SoED_full-report.pdf

UNWTO (2019). *Yearbook of Tourism Statistics, Data 2013 – 2017, 2019 Edition*, UNWTO, Madrid. doi: 10.18111/9789284420414

Urgeles R., and Camerlenghi A. (2013). Submarine landslides of the Mediterranean Sea: Trigger mechanisms, dynamics, and frequency-magnitude distribution. *Journal of Geophysical Research: Earth Surface*, *118*(4), 2600–2618. doi: 10.1002/2013jf002720

USGS (2006). Tsunami Hazards—A National Threat. In *Fact Sheet 2006–3023*. U.S. Geological Survey. https://pubs.usgs.gov/fs/2006/3023/

Vafeidis A., Abdulla A., Bondeau A., Brotons L., Ludwig R., Portman M., Reimann L., Vousdoukas M., and Xoplaki E. (2020). Managing Future Risks and Building Socio-Ecological Resilience. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental change in the Mediterranean Basin - Current Situations and Risks for the Future*. Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, pp. 539-588. doi: 10.5281/zenodo.7101119

Vargas-Yáñez M., Jesús García M., Salat J., García-Martínez M. C., Pascual J., and Moya F. (2008). Warming trends and decadal variability in the Western Mediterranean shelf. *Global and Planetary Change*, *63*(2–3). doi: 10.1016/j.gloplacha.2007.09.001

Verdura J., Linares C., Ballesteros E., Coma R., Uriz M. J., Bensoussan N., and Cebrian E. (2019). Biodiversity loss in a Mediterranean ecosystem due to an extreme warming event unveils the role of an engineering gorgonian species. *Scientific Reports*, *9*(1), 5911. doi: 10.1038/s41598-019-41929-0

Viaroli P., Soana E., Pecora S., Laini A., Naldi M., Fano E. A., and Nizzoli D. (2018). Space and time variations of watershed N and P budgets and their relationships with reactive N and P loadings in a heavily impacted river basin (Po river, Northern Italy). *Science of The Total Environment*, *639*, 1574–1587. doi: 10.1016/j.scitotenv.2018.05.233

Vicente-Serrano S. M., Domínguez-Castro F., Murphy C., Hannaford J., Reig F., Peña-Angulo D., Tramblay Y., Trigo R. M., Mac Donald N., Luna M. Y., Mc Carthy M., Van Der Schrier G., Turco M., Camuffo D., Noguera I., García-Herrera R., Becherini F., Della Valle A., Tomas-Burguera M., and El Kenawy A. (2021). Long-term variability and trends in meteorological droughts in Western Europe (1851–2018). *International Journal of Climatology*, *41*(S1). doi: 10.1002/joc.6719

Vilibić I., Denamiel C., Zemunik P., and Monserrat S. (2021). The Mediterranean and Black Sea meteotsunamis: an overview. *Natural Hazards*, *106*(2), 1223–1267. doi: 10.1007/s11069-020-04306-z

Vilibić I., Šepić J., Dunić N., Sevault F., Monserrat S., and Jordà G. (2018). Proxy-Based Assessment of Strength and Frequency of Meteotsunamis in Future Climate. *Geophysical Research Letters*, *45*(19). doi: 10.1029/2018GL079566

Vousdoukas M. I., Mentaschi L., Voukouvalas E., Verlaan M., and Feyen L. (2017). Extreme sea levels on the rise along Europe's coasts. *Earth's Future*, *5*(3), 304–323. doi: 10.1002/2016ef000505

Wahl T., and Chambers D. P. (2015). Evidence for multidecadal variability in US extreme sea level records. *Journal of Geophysical Research: Oceans*, *120*(3), 1527–1544. doi: 10.1002/2014jc010443

Wallentinus I., and Nyberg C. D. (2007). Introduced marine organisms as habitat modifiers. *Marine Pollution Bulletin*, *55*(7–9). doi: 10.1016/j.marpolbul.2006.11.010

Walsh K., Giorgi F., and Coppola E. (2014). Mediterranean warm-core cyclones in a warmer world. *Climate Dynamics*, *42*(3–4), 1053–1066. doi: 10.1007/S00382-013-1723-y

Wilkinson J. L., Boxall A. B. A., Kolpin D. W., Leung K. M. Y., Lai R. W. S., Galban-Malag C., Adell A. D., Mondon J., Metian M., Marchant R. A., Bouzas-Monroy A., Cuni-Sanchez A., Coors A., Carriquiriborde P., Rojo M., Gordon C., Cara M., Moermond M., Luarte T., ... Teta C. (2022). Pharmaceutical pollution of the world's rivers. *Proceedings of the National Academy of Sciences of the United States of America*, *119*(8). doi: 10.1073/pnas.2113947119

Wimart-Rousseau C., Wagener T., Álvarez M., Moutin T., Fourrier M., Coppola L., Niclas-Chirurgien L., Raimbault P., D'Ortenzio F., Durrieu de Madron X., Taillandier V., Dumas F., Conan P., Pujo-Pay M., and Lefèvre D. (2021). Seasonal and Interannual Variability of the CO2 System in the Eastern Mediterranean Sea: A Case Study in the North Western Levantine Basin. *Frontiers in Marine Science*, *8*. doi: 10.3389/fmars.2021.649246

WMO (1992). *International meteorological vocabulary* (WMO-No. 182). Secretariat of the World Meteorological Organization. https://library.wmo.int/idurl/4/35809

WMO (2023). *Guidelines on the Definition and Characterization of Extreme Weather and Climate Events. WMO-No. 1310.* WMO, Geneva, Switzerland.

WMO, Tank A., Zwiers F., and Zhang X. (2009). Guidelines on Analysis of Extremes in a Changing Climate in Support of Informed Decisions for Adaptation. WMO-TD No. 150. In *World Meteorological Organization*. WMO, Geneva, Switzerland. https://library.wmo.int/idurl/4/48826

Wolff C., Nikoletopoulos T., Hinkel J., and Vafeidis A. T. (2020). Future urban development exacerbates coastal exposure in the Mediterranean. *Scientific Reports*, *10*(1), 14420. doi: 10.1038/s41598-020-70928-9

Woodworth P. L., Melet A., Marcos M., Ray R. D., Wöppelmann G., Sasaki Y. N., Cirano M., Hibbert A., Huthnance J. M., Monserrat S., and Merrifield M. A. (2019). Forcing Factors Affecting Sea Level Changes at the Coast. *Surveys in Geophysics*, *40*(6), 1351–1397. doi: 10.1007/s10712-019-09531-1

Wöppelmann G., and Marcos M. (2016). Vertical land motion as a key to understanding sea level change and variability. *Reviews of Geophysics*, *54*(1), 64–92. doi: 10.1002/2015rg000502

Xoplaki E., Ellsäßer F., Grieger J., Nissen K. M., Pinto J., Augenstein M., Chen T.-C., Feldmann H., Friederichs P., Gliksman D., Goulier L., Haustein K., Heinke J., Jach L., Knutzen F., Kollet S., Luterbacher J., Luther N., Mohr S., … Wolf F. (2023). *Compound events in Germany in 2018: drivers and case studies*. doi: 10.5194/egusphere-2023-1460

Yeste P., Rosa-Cánovas J. J., Romero-Jiménez E., García-Valdecasas Ojeda M., Gámiz-Fortis S. R., Castro-Díez Y., and Esteban-Parra M. J. (2021). Projected hydrologic changes over the north of the Iberian Peninsula using a Euro-CORDEX multi-model ensemble. *Science of The Total Environment*, *777*, 146126. doi: 10.1016/j.scitotenv.2021.146126

Zanchettin D., Bruni S., Raicich F., Lionello P., Adloff F., Androsov A., Antonioli F., Artale V., Carminati E., Ferrarin C., Fofonova V., Nicholls R. J., Rubinetti S., Rubino A., Sannino G., Spada G., Thiéblemont R., Tsimplis M., Umgiesser G., … Zerbini S. (2021). Sea-level rise in Venice: historic and future trends (review article). *Natural Hazards and Earth System Sciences*, *21*(8), 2643–2678. doi: 10.5194/nhess-21-2643-2021

Zenetos A., Albano P. G., Garcia E. L., Stern N., Tsiamis K., and Galanidi M. (2022). Established non-indigenous species increased by 40% in 11 years in the Mediterranean Sea. *Mediterranean Marine Science*, *23*(1), 196–212. doi: 10.12681/mms.29106

Zenetos A., Çinar M. E., Crocetta F., Golani D., Rosso A., Servello G., Shenkar N., Turon X., and Verlaque M. (2017). Uncertainties and validation of alien species catalogues: The Mediterranean as an example. *Estuarine, Coastal and Shelf Science*, *191*, 171–187. doi: 10.1016/j.ecss.2017.03.031

Zenetos A., and Galanidi M. (2020). Mediterranean non-indigenous species at the start of the 2020s: recent changes. *Marine Biodiversity Records*, *13*(1), 10. doi: 10.1186/s41200-020-00191-4

Zhan S., Song C., Wang J., Sheng Y., and Quan J. (2019). A Global Assessment of Terrestrial Evapotranspiration Increase Due to Surface Water Area Change. *Earth's Future*, *7*(3), 266–282. doi: 10.1029/2018ef001066

Zhang L., Wu P., Zhou T., Roberts M. J., and Schiemann R. (2016). Added value of high resolution models in simulating global precipitation characteristics. *Atmospheric Science Letters*, *17*(12), 646–657. doi: 10.1002/asl.715

Zingone A., Escalera L., Aligizaki K., Fernández-Tejedor M., Ismael A., Montresor M., Mozetič P., Taş S., and Totti C. (2021). Toxic marine microalgae and noxious blooms in the Mediterranean Sea: A contribution to the Global HAB Status Report. *Harmful Algae*, *102*, 101843. doi: 10.1016/j.hal.2020.101843

Zittis G., Bruggeman A., and Lelieveld J. (2021). Revisiting future extreme precipitation trends in the Mediterranean. *Weather and Climate Extremes*, *34*, 100380. doi: 10.1016/j.wace.2021.100380

Information about the authors

Coordinating Lead Authors

Murat BELIVERMIS, Department of Biology, Faculty of Science, Istanbul University, *Istanbul, Türkiye*
Dario CAMUFFO, National Research Council of Italy (CNR), Institute of Atmospheric Sciences and Climate, *Padua, Italy*

Lead Authors

Nuno CAIOLA, Department of Climate Solutions and Ecosystem Services, Eurecat, *Amposta, Spain*
Claudio FERRARI, Department of Economics, University of Genoa, *Genoa, Italy*
Nadia MHAMMDI, Institut Scientifique, University Mohammed V of Rabat, *Rabat, Morocco*
Estela ROMERO, Global Ecology Unit, Centre for Ecological Research and Forestry Applications (CREAF), *Barcelona, Spain*
Claudia WOLFF, Institute of Geography, Kiel University, *Kiel, Germany*

Contributing Authors

Vincenzo ASERO, Department of Political and Social Sciences, University of Catania, *Catania, Italy*
Sana BEN ISMAIL, Institut National des Sciences et Technologies de la Mer, *Tunis, Tunisia*
Cem DALYAN, Department of Biology, Faculty of Science, Istanbul University, *Istanbul, Türkiye*
Hamouda DAKHLAOUI, University of Tunis El Manar, National Engineering School of Tunis, Laboratory of Modelling in Hydraulics and Environment, *Tunis, Tunisia* / University of Carthage, National School of Architecture and Urban Planning of Tunis, *Sidi Bou Said, Tunisia*
Lena REIMANN, Instituut voor Milieuvraagstukken (IVM) – Institute for Environmental Studies, Faculty of Science, Vrije Universiteit Amsterdam (VU), *Amsterdam, The Netherlands*
Alessio TEI, Department of Economics | DIEC, University of Genoa, *Genoa, Italy*
Matteo VACCHI, Department of Earth Sciences, University of Pisa, *Pisa, Italy*
Antonio della VALLE, Institute of Atmospheric Sciences and Climate, National Research Council of Italy (CNR-ISAC), *Padua, Italy*

Impacts and risks

3

Coordinating Lead Authors:
Z. Selmin BURAK *(Türkiye)*, **Nathalie HILMI** *(Monaco)*, **José A. JIMÉNEZ** *(Spain)*

Lead Authors:
Elham ALI *(Egypt)*, **Mario V BALZAN** *(Malta)*, **Alessandra BONAZZA** *(Italy)*,
Marie-Yasmine DECHRAOUI BOTTEIN *(France)*, **Nazli DEMIREL** *(Türkiye)*,
Shekoofeh FARAHMAND *(Iran)*, **Mauricio GONZÁLEZ** *(Spain)*,
Sebastián MONTSERRAT *(Spain)*, **David PULIDO-VELAZQUEZ** *(Spain)*,
Alain SAFA *(France)*, **Matteo VACCHI** *(Italy)*

Contributing Authors:
Ignacio AGUIRRE AYERBE *(Spain)*, **Iñigo ANIEL-QUIROGA** *(Spain)*,
Nuno CAIOLA *(Spain)*, **Emma CALIKANZAROS** *(France)*, **Dario CAMUFFO** *(Italy)*,
Mine CINAR *(USA)*, **María Carmen LLASAT** *(Spain)*, **Alban THOMAS** *(France)*

This document should be cited as:
Burak, Z.S., Hilmi, N., Jiménez, J.A., Ali, E., Balzan, M.V., Bonazza, A., Dechraoui-Bottein, M.-Y., Demirel, N. Farahmand, S., González, M., Montserrat, S., Pulido-Velázquez, D., Safa, A., Vacchi, M., 2024: Impacts and Risks. In: *Climate and Environmental Coastal Risks in the Mediterranean.* [Djoundourian, S., Lionello, P., Llasat, M.C., Guiot, J., Cramer, W., Driouech, F., Gattacceca, J.C., Marini, K. (eds.)]. MedECC Reports. MedECC Secretariat, Marseille, France, pp. 131-208, doi: 10.5281/zenodo.15096247

3

Chapter 3

Impacts and risks

Executive Summary

This chapter gives a comprehensive overview of the main coastal impacts and risks affecting Mediterranean coasts. Due to their importance and potential impact on the Mediterranean coastal system, the main risks covered are erosion, flooding, water-related risks (e.g. saltwater intrusion and pollution), and biological risks. They are analysed at different time scales associated with drivers of different origin, as described in *Chapter 2*. The different risks under current conditions and under the effect of climate change are characterised, providing the respective magnitude for the Mediterranean and identifying coastal hotspots. The main impacts induced by analysed drivers and hazards are characterised by considering their potential effects on the economy (related to main economic sectors in the Mediterranean coastal zone such as tourism, agriculture, and fisheries), ecology (impacts on representative habitats and ecosystems such as deltas, wetlands, and seagrass) and on the human system (cultural heritage and human health).

It is important to bear in mind that some of the economic activities potentially affected by analysed hazards, such as coastal tourism, are also drivers of impacts along the Mediterranean coastal system. The current picture for the Mediterranean Basin is a coastal fringe affected by multiple hazards, with significant exposure due to the socio-economic-cultural setting of the Mediterranean with high population density and concentration of assets and relatively high vulnerability due to the decrease in natural coastal resilience.

Coastal erosion {3.2.2}

The Mediterranean coastline is currently experiencing significant long-term erosion. Based on observed rates, the median projected shoreline retreat by 2100 compared to 2010 is estimated to be 17 m, with *very likely* (5th, 95th percentiles) values between −32 m and −1 m. This trend presents significant spatial variability, with the western Mediterranean concentrating the largest regional erosion hotspots, which are mainly located in river mouth areas and coastal stretches around harbours and other coastal infrastructure. This erosion will increase under the effect of climate change, as sea level rise (SLR) will induce widespread shoreline retreat *(very high confidence)*. The estimated median value of SLR-induced shoreline retreat for the Mediterranean with respect to 2010, is −17.5 m and −23 m by 2050 under the IPCC AR5 RCP4.5 and RCP8.5 scenarios, respectively, increasing to −40 m and −65 m respectively by the year 2100. Although shoreline retreat is certain, there is significant uncertainty regarding the computed induced rates due to the models used. Nevertheless, this SLR-induced component must be considered in addition to ongoing shoreline evolution rates.

In the absence of adaptation and protection measures, Mediterranean beaches will continuously erode over the next decades. In urbanised areas, where the coast is limited by physical barriers, this will lead to the progressive narrowing and eventual disappearance of beaches. This constitutes a high risk for intensive sun-and-beach tourism areas due to the expected decrease in beach carrying capacity and the associated economic impacts *(very likely)*.

The progressive narrowing of beaches will reduce the degree of protection provided to existing infrastructure along the coast, with the corresponding increase in the risk of storm induced damage. Therefore, even despite the absence of any significant increasing trend in storm intensity and frequency, storm-induced damage will increase *(very likely)* over the next decades along the Mediterranean coast.

Coastal flooding {3.2.3}

In the Mediterranean, coastal flooding from coastal storms is mainly caused by waves, due to the relatively low magnitude of surges. The most exposed areas are waterfronts and the more seaward parts of urban developments. The highest-risk areas show significant spatial variability, depending on local storm climate and the extent and dimensions of existing natural and human defences.

In the future, SLR will *very likely* increase the frequency and magnitude of storm-induced flooding along the Mediterranean coastal zone due to an increase in the total water level at the shoreline, leading to an increase in the existing risk in the absence of adaptation and protection measures. This effect will be more significant in low-lying areas and will be enhanced by the decrease in protection due to beach erosion.

SLR will result in the gradual and permanent inundation of low-lying unprotected areas *(high confidence)*. Within the Mediterranean Basin, deltas and coastal plains are particularly vulnerable, as subsidence can locally and significantly increase relative sea level rise. These areas, often home to the highest natural values in the Mediterranean coastal zone, while being also used for agriculture, are at the greatest risk from relative sea level rise (RSLR).

The Mediterranean Basin is one of the areas in Europe where disastrous flash floods caused by intense precipitation events are more frequent, mainly affecting river mouths and coastal areas. This is due to local climate and topographic conditions, and the existing high population and urban settlements in flood-prone areas. In the future, without adaptation measures, the risk is *likely* to increase due to more frequent heavy rainfall episodes linked to climate change and the continuous growth of urban areas along the coast, although showing large spatial variability *(medium confidence)*.

The Mediterranean coast is one of the areas in Europe at highest risk to compound flooding due to co-occurrence of heavy rainfall and high-water levels. The expected evolution of these events under climate change shows large spatial variability in their occurrence without a clear trend regarding their intensity *(medium confidence)*.

SLR will increase the extreme total water level at the shoreline and the associated flood risk. However, except for certain localised areas like the northern Adriatic, the Mediterranean stands out among European coastlines for experiencing relatively low extreme total water levels under SLR *(high confidence)*. The Mediterranean region is particularly vulnerable to coastal flooding, due to the widespread presence of unprotected buildings and activities along the Mediterranean coastline, and the relatively small values of maximum coastal water levels. In the absence of coastal protection or adaptation, climate change will very likely be the main driver of future increase in coastal flood losses.

Tsunamis and meteotsunamis {3.2.4}

Due to the high seismicity of the Mediterranean Basin, the short travel times of tsunami waves to the coast from source areas and the high population density and concentration of assets along the coast, tsunamis are a significant threat for Mediterranean coastal zones despite their low frequency, with the eastern Mediterranean being the most affected area.

Meteotsunamis occur regularly on the Mediterranean coast and show large spatial variability, with their highest intensities in bays and inlets where resonance is favoured. As a result, the greatest damage and, consequently, the areas of highest risk, are concentrated in local hotspots where existing coastal infrastructure and developments are not adapted to accommodate significant changes in sea level. Despite this, hazard assessments are only available for a few areas, while risk assessments are lacking.

Freshwater resource scarcity {3.2.5}

Without appropriate adaptation and protection strategies, the quantity and quality of freshwater resources in coastal areas will decline, reducing the water available for future uses *(very likely)*.

Maintaining the socio-economic activities related to the significant urban, agricultural and/or industrial development in Mediterranean coastal areas, which require supplying significant freshwater demands, will be a challenging issue which will be exacerbated due to seawater intrusion in coastal aquifers. In the future, associated risks will be amplified due to the expected reduction in aquifer recharge, sea level rise, the increase in water demands and the frequency and severity of droughts.

The use of unconventional water resources generated by desalination will reduce the risk of water scarcity and their socio-economic implications, but it may increase the risks of environmental impacts, especially on coastal ecosystems (e.g. adverse impact due to brine water discharge) and will increase associated CO_2 emissions.

***Coastal pollution risks* {3.2.6}**

Water pollution along the Mediterranean coast is mainly generated by land-based point and diffuse sources (80%) due to the existing high urbanisation of the coastal zone, with ship-induced and air pollution contributing the remaining part. This puts the coastal zone at risk of impacts on ecological systems and human health due to diverse pollutants generated either on land and discharged into the coastal waters or accidental oil spills.

Along the Mediterranean coast there are numerous sites that present a high risk associated with eutrophication of coastal waters due to nutrient inputs from land. Coastal eutrophication is of medium or important significance in 13 Mediterranean countries. This has adverse impacts on coastal ecosystems and may also have significant local socio-economic impacts due to its impact on aquaculture, fishing and coastal tourism. In the future, it is expected that the risk along the Mediterranean coasts will increase following the expected increase in their occurrence and the increasing pressure on the coastal zone *(high confidence).*

The presence of areas with high concentrations of plastics along the Mediterranean coast has high adverse impacts on marine biodiversity and human health due to the ingestion and accumulation by marine fish.

Synergistic interactions between climate change impacts and emerging pollutants in the coastal environment will become more frequent *(medium confidence)* due to multiple stressors from both natural and anthropogenic sources.

Accumulated pollution from various sources in coastal and bathing waters endangers coastal ecosystems and human health. The magnitude of anthropogenic impacts has been higher in coastal waters compared to offshore waters due to the increasing anthropogenic pressure (e.g. overfishing, land-based pollution) on coastal zones and climate change as prevailing pressures altogether *(medium confidence).*

***Biological risks* {3.2.7}**

The Mediterranean coastal zone is subjected to a high risk associated with invasive non-indigenous species that produce different ecological and socio-economic impacts through their interaction with native species, which significantly affect native biodiversity. In addition, there is strong evidence that most of the services provided by Mediterranean marine ecosystems are affected by invasive non-indigenous species, those related to food provision being the most impacted ones *(high confidence).*

The massive abundance of jellyfish is a threat to anthropogenic coastal activities and human health due to their competitiveness and predatory impacts on marine biodiversity and their multiple direct and indirect consequences. Jellyfish blooms have potential adverse impacts on the marine ecosystem with consequent health risks for marine organisms and humans because they represent vectors of potential bacterial pathogens affecting fish aquaculture, in particular.

Mass mortality events (MMEs) are attributed to the increase in frequency and intensity of marine heat waves (MHWs) and pathogen infections. The frequency and intensity of MMEs will *likely* increase in the future in parallel with rising MHWs *(high confidence).*

The frequency of the mucilage phenomenon has been reported to have increased significantly over the last decades. Mucilage adversely affects seawater and makes it unsuitable for bathing due to the adherence of this mucus-like substance on bathers' skin. Marine mucilage settled on the benthos in the form of large aggregates, coats the sediment, causing hypoxic and/or anoxic conditions resulting in the suffocation of benthic organisms. The mucilage phenomenon can cause serious economic damage to tourism and fisheries *(high confidence).*

***Impacts on the economic system* {3.3}**

Coastal tourism along the Mediterranean is *likely* to be affected by climate change due to a decrease in climate comfort during the summer season and its increase in spring and autumn *(medium confidence).* In addition to this, sun-and-beach tourism will be negatively affected by the decrease in beach carrying capacity due to SLR-induced beach erosion. This will result in the risk of a substantial decrease in revenue for coastal communities and consequently declines in GDPs of countries in the region *(medium confidence).*

Without effective adaptation, agriculture production in Mediterranean coastal zones will be negatively affected by climate change due to the expected decline in water resources, soil degradation, and increase in salinity. This can directly affect food security *(medium level).*

There is a *high agreement* that Mediterranean fisheries are overexploited, and the majority of the commercial stocks are declining. In addition, the risk of traditional fish stocks shrinking in quantity and economic value is further increased by pollution and widespread emergence of non-indigenous species. This represents a financial and technical challenge for many artisanal fishermen, who are the main operators in coastal fisheries *(high confidence).*

Climate change exacerbates challenges related to water and energy security through increasing temperatures, as well as decreasing precipitation and enhanced droughts *(high confidence).*

The risk for coastal infrastructure along the Mediterranean due climate change in general, and SLR in particular is related to the decrease in their functionality, mainly associated with increased coastal flooding and overtopping. For Mediterranean ports, the expected change in risk level by 2100 will be small under low-medium SLR scenarios, but it will significantly increase becoming high or very high under the RCP8.5 scenario *(medium confidence).* Although an increase in risk associated with decreased functionality of coastal protection infrastructure due to SLR is expected at basin scale *(high confidence),* its significance will depend on its specific local configurations.

Impacts on the human system {3.4}

A large part of the existing UNESCO cultural World Heritage Sites (WHS) in the low elevation coastal zone of the Mediterranean are currently at risk to erosion and coastal flooding *(medium confidence),* with an expected increase in flood and erosion risk that will reach 50% and 13% higher values respectively by 2100 under a high-end SLR scenario *(unlikely).* Additionally, the built heritage is *likely* to be affected by climate change through slow cumulative deterioration processes. As a result, the risk of decohesion and fracturing in porous building materials is expected to increase.

The occurrence of natural disasters and environmental degradation linked to pollution have multiple direct and indirect impacts on the health and well-being of coastal populations along the Mediterranean Basin *(high confidence).* In the absence of adaptation, their impacts are expected to increase in the near future due to the expected increase in hazardous conditions due to climate change and rising coastal population *(medium confidence).*

Impacts on the natural system {3.5}

Mediterranean coastal wetlands have significantly declined during the 20th century due to a combination of erosion, extreme events, salt-water intrusion, and mainly human-induced pressures such as the expansion of irrigated agriculture and urban development. They are projected to be significantly affected by future changes in precipitation *(high agreement, medium evidence),* although with high spatial variability. SLR-induced hazards are expected to result in the loss of coastal wetlands *(high agreement, robust evidence),* with locally significant impacts in areas where rigid inland boundaries limit their potential for horizontal migration.

SLR-induced erosion along the Mediterranean coast will induce a decline in ecosystem services provided by coastal habitats, as these areas degrade and, eventually, disappear with ongoing erosion *(high confidence).* For the northern Mediterranean coast, a decline in approximately 5% in services by 2100 relative to current conditions under RCP8.5 has been estimated *(medium confidence),* presenting a high spatial variability; the eastern Mediterranean is expected to experience the largest declines.

Changes in sediment supply, industrial development, and urban processes will enhance the vulnerability of natural coastal ecosystems (e.g. sandy coastal sandy beaches, saltmarshes, coastal lagoons) to sea level rise. In addition, coastal systems are experiencing compound threats from ocean warming, sea level rise, eutrophication, and the expansion of low-oxygen zones as a result of climate change. The risk to these ecosystems is projected to become very high by the end of the century.

3

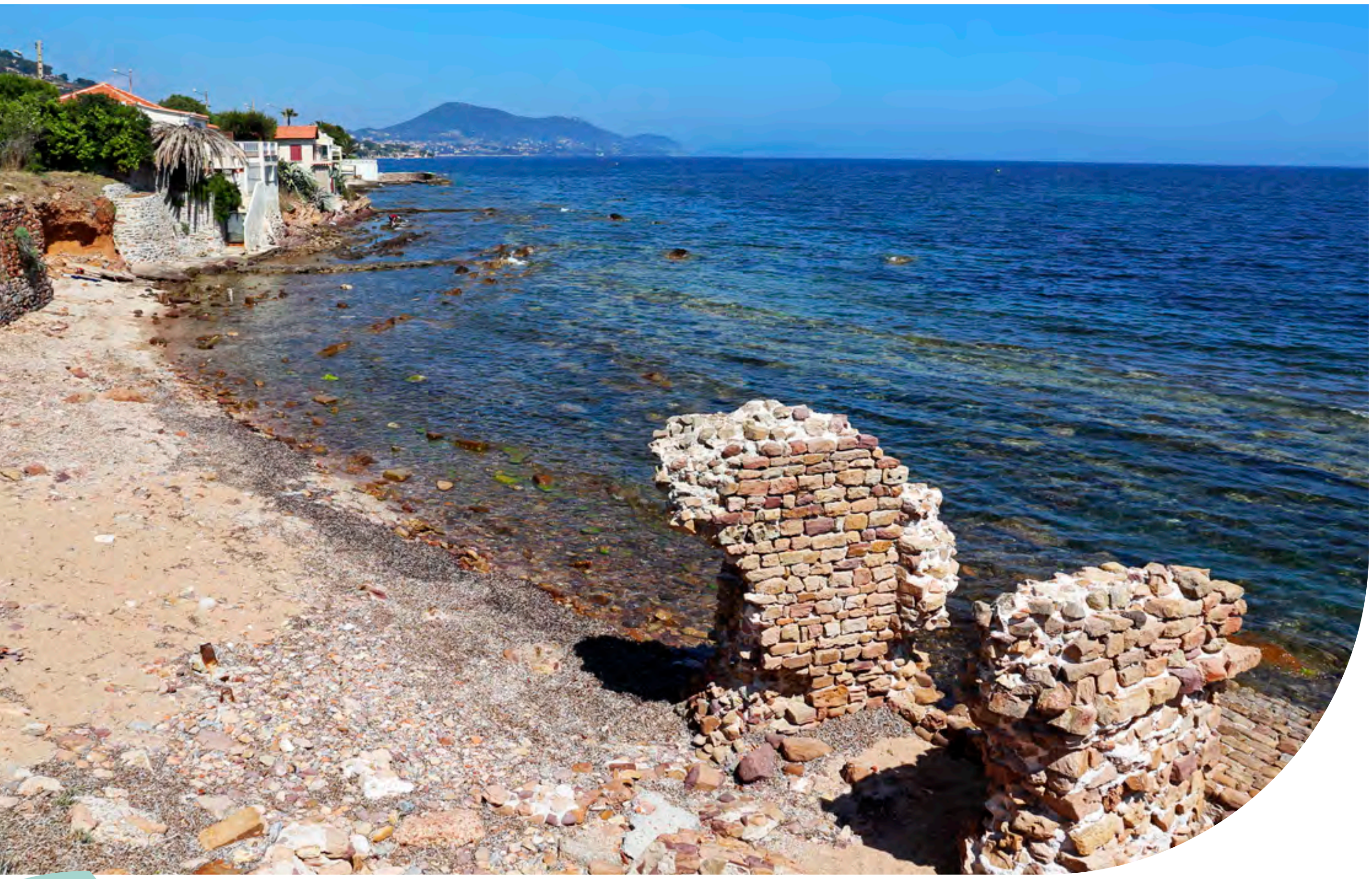
3.1 Introduction

The Mediterranean Basin is generally characterised by a narrow and highly populated coastal area. In the second half of the 20th century, the Mediterranean population has doubled from 240 million to 480 million (UNEP/MAP 2016) and the human pressure on the coasts is further amplified by increased international tourism. The Mediterranean coastal zone is therefore characterised by an increased pressure from human activities, but also subject to future global environmental change as the Mediterranean area is considered a hotspot of current climate change (Giorgi 2006; Guiot and Cramer 2016; MedECC 2020b; Ali et al. 2022). This may result in high sea-level rise rates compared to global averages, leading to significant losses in the environmental, cultural and economic values of Mediterranean coasts (Vacchi et al. 2021).

Mediterranean sea level rise will lead to more frequent flooding of low-lying coastal areas through storm surges, wave extremes and, in minor terms, through higher tides (See *Chapter 2, Section 2.2.4*). Robust knowledge on current and future coastal risks enables Mediterranean policymakers to anticipate impacts that could be triggered by the multiple effects of climate change.

The assessment of impact and vulnerability is required in the framework of Integrated Coastal Zone Management (ICZM) Protocol of the Barcelona Convention (UNEP/MAP and PAP/RAC 2008). The integration of information from various fields including physical, ecological and socio-economic disciplines is a prerequisite for any coastal impact assessment and for planning appropriate future interventions along the Mediterranean shores (Wolff et al. 2018).

Due to the high natural, cultural and socio-economic values that might be threatened or lost in Mediterranean coastal areas, several efforts have been made by the scientific community to produce future climate drivers including sea level scenarios (see *Chapter 2*) which may determine the magnitude of problems that different Mediterranean coastal areas may have to face, as well as possible solutions.



3.2 Main risks in coastal areas

3.2.1 Coastal risks – general

The Mediterranean can be considered a region with a high coastal risk due to the combination of multiple hazards such as erosion, flooding, pollution and biological hazards (e.g. Sánchez-Arcilla et al. 2011; Sarkar et al. 2022), a highly sensitive coast and increasing exposure due to urban development (e.g. Wolff et al. 2020), a high concentration of coastal dependent economic sectors such as tourism (Plan Bleu 2022) and valuable ecosystem services (Liquete et al. 2016).

Due to this, multi-hazard risk assessments have become an important tool for understanding and mitigating their potential impacts. However, due to the large diversity in risk components along the Mediterranean coast, most of the existing risk assessments are local (e.g. Torresan et al. 2012; Roukounis and Tsikriktsis 2022), or they analyse single hazards and some consequences (e.g. Reimann et al. 2018a). Therefore, most of studies covering large areas in the Mediterranean evaluated the coastal vulnerability instead of the coastal risk, that is the potential of the coastal system to be harmed by the considered hazards (e.g. Snoussi et al. 2009; Torresan et al. 2012; Hereher 2015; Satta et al. 2017). Satta et al. (2017) developed one of the few multi-risk assessments at the Mediterranean scale using an index approach to characterise hazards, vulnerability and exposure. Their analysis focuses on risks associated with erosion and flooding induced by different drivers and results are given in a 5-class qualitative scale from extremely high to extremely low risk. Obtained results characterise the Mediterranean coast with a heterogeneous spatial distribution of the risk, in the form of hotspots, mostly determined by the diversity in values to exposure and vulnerability (e.g. coastal geomorphology) *(Figure 3.1).*

3.2.2 Coastal erosion risks

One of the most common coastal risks is that induced by shoreline erosion, which currently affects a large extent of the world's sandy coasts (Luijendijk et al. 2018; Mentaschi et al. 2018) and may be exacerbated by climate change (e.g. Nicholls and Cazenave 2010), threatening the survival of many sandy beaches (Vousdoukas et al. 2020) and affecting the functions

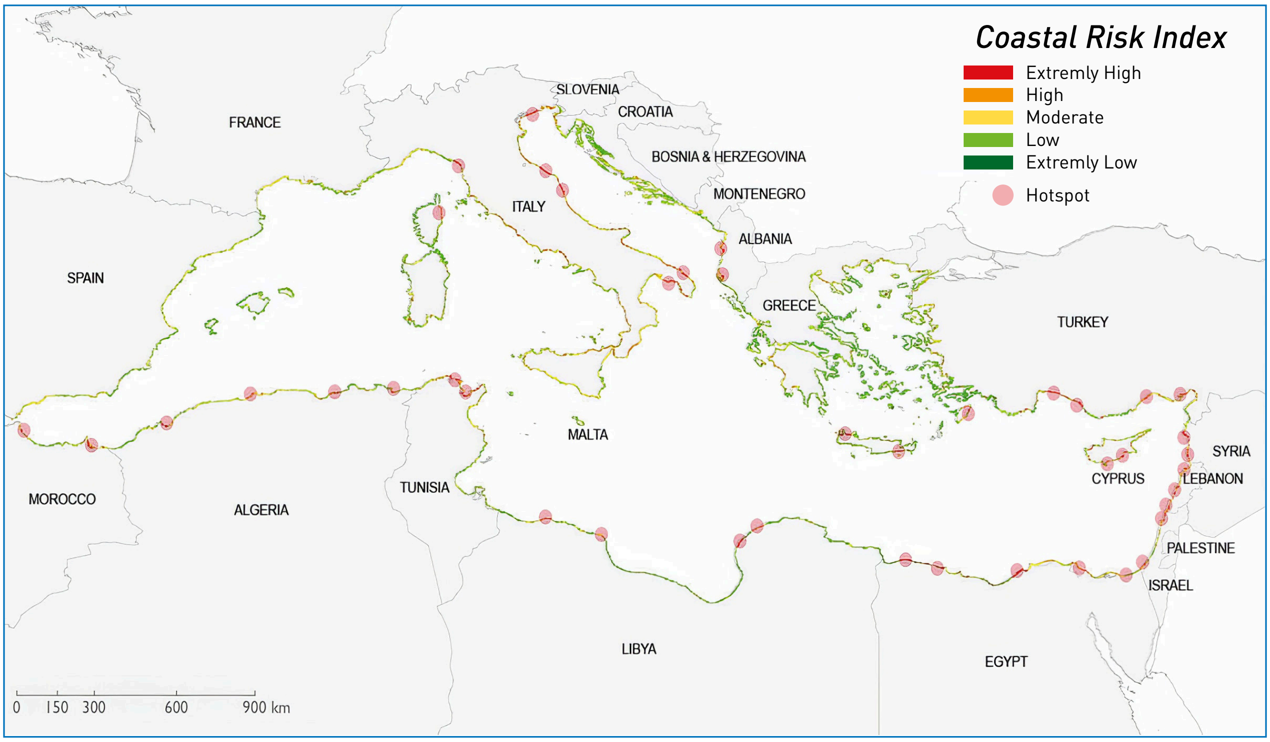


Figure 3.1 | Coastal Risk Index map of the Mediterranean. Source: Satta et al. (2017).

they provide (Defeo et al. 2009; Roebeling et al. 2013; MedECC 2020a). The drivers and factors that control and determine coastal erosion, interact along the coast and operate at different timescales, such that to adequately characterise erosion requires doing so at multiple scales (e.g. Ballesteros et al. 2018; Vousdoukas et al. 2020). Many beaches along the Mediterranean are currently retreating and will significantly narrow and eventually disappear by the end of the 21st century. Vousdoukas et al. (2020) using the data from Luijendik et al. (2018) and Mentaschi et al. (2018) obtained for the entire Mediterranean Basin a median shoreline retreat[32] of −17 m by 2100, with *very likely* values between −32 m and −1 m. These values presented large spatial variability, although existing regional-scale analyses highlight the relevance of shoreline erosion around the Basin. Thus, Jiménez and Valdemoro (2019) estimated that about 67% of the sandy shoreline of the Catalan coast (northwestern Mediterranean, Spain) is eroding at an average erosion rate of −1.6 m yr^{-1}, whereas the regional average shoreline evolution is around −0.4 m yr^{-1}. Similarly, Pranzini (2018), using data from the Italian National Table on Coastal Erosion 'Tavolo Nazionale sull'Erosione Costiera' (MATTM-Regioni 2018) reported that about 50% of Italian sandy beaches are currently experiencing erosion despite the implementation of coastal protection projects. Along the southern Mediterranean coast, (Amrouni et al. 2019) estimated that about 70% of sandy beaches along the Hammamet Gulf (Tunisia) are persistently eroding at an average rate exceeding −0.5 m yr^{-1}.

Current erosion hotspots[33] are mainly located in river mouth areas and coastal stretches around harbours and other coastal infrastructure. In the first case, river mouth areas are a direct consequence of one of the main terrestrial drivers affecting coastal stability, the decrease in river sediment supplies as a result of human-induced modifications to river basins (e.g. Syvitski et al. 2005). Therefore, about 75% of the deltaic coastlines in the Mediterranean are retreating (Besset et al. 2019), and they comprise areas with the largest local erosion rates along the Mediterranean coastline such as Cap Tortosa at the Ebro delta, Spain (35 m yr^{-1} from 1957 to 2013; Ramírez-Cuesta et al. 2016); areas near the mouth of the Petit Rhône, France (10 m yr^{-1} from 1960 to 2000; Sabatier and Suanez 2003); the Medjerda delta, Tunisia (up to 42 m yr^{-1}, from 1972 to 2013; Louati et al. 2015); Moulouya delta, Morocco (up to 10 m yr^{-1}, from 1958 to 2006; Mouzouri and Irzi 2011); Ombrone delta, Italy (10 m yr^{-1} up to 2013–16; Mammì et al. 2019), and Damietta promontory at the Nile delta, Egypt (42 m yr^{-1}, 1972–1990; Dewidar and Frihy 2007); before the implementation of coastal stabilisation works. In the second case, stretches surrounding harbours and marinas are the result of the modification of coastal dynamics by existing coastal infrastructure. Examples of such hotspots associated with large infrastructure are found at the ports of Tangier, Morocco (Sedrati and Anthony 2007) and Valencia, Spain (Pardo-Pascual and Sanjaume 2019), or with the existence of several marinas along coastal regions such as in Tuscany, Italy (Anfuso et al. 2011); in Catalonia, Spain (Jiménez and Valdemoro 2019); and Greece (Tsoukala et al. 2015).

Future changes in decadal-scale shoreline erosion will be determined by the projected changes in corresponding drivers. With respect to the contribution of waves, as mentioned in *Chapter 2*, existing projections under different scenarios predict a slight decrease in significant wave height and in storminess for the Mediterranean. This would imply that, in the worst case, the magnitude of coastal dynamics along the Mediterranean will tend to decrease slightly. However, there are some regional studies such as Casas-Prat and Sierra (2012) for the Catalan coast, which have estimated more significant changes in wave direction than in wave height. This discrepancy in the contribution of wave drivers will introduce significant uncertainty in the projection of coastal dynamics, as it does not depend on one, but on a set of wave parameters, which may lead to opposite changes in sediment transport. In this sense, the expected changes in wave height and wave direction may lead to opposite changes in longshore sediment transport and have to be estimated locally (Casas-Prat et al. 2016).

---

[32] These values were estimated by extrapolating obtained shoreline evolution rates from satellite images over two decades to the end of the century without including SLR or any additional changes in drivers.

[33] Erosion hotspots are coastal locations where erosion rates are significantly higher than in surrounding areas.

With respect to the contribution of river sediment supplies, existing estimations of average sediment delivery for 21st century climate warming scenarios predict an 11–16% increase (Moragoda and Cohen 2020), while for deltas, projected changes predict mean and maximum declines of 38% and 83% respectively between 1990–2019 and 2070–2099 (Dunn et al. 2019). The final contribution will be the result of the balance between climate-induced changes and human-modifications in river basins (Syvitski et al. 2022).

Finally, the estimated increase of human occupation and use of coastal areas along the Mediterranean for the next decades (e.g. see *Chapter 2, Section 2.6*) will *likely* contribute to altering coastal dynamics patterns and reducing the existing accommodation space along the coast due to the construction of coastal infrastructure. However, this will depend on the level of existing artificialisation along the coast, as the already highly developed areas have shown attenuation in the increase of armouring as observed in the Mediterranean coast of Andalusia (Spain) (Manno et al. 2016).

Superimposed on current evolution rates, sandy shorelines will be directly affected by relative sea level rise (RSLR), inducing additional shoreline retreat. Unlike current conditions, this general retreat will vary spatially, depending on local RSLR values, existing geomorphology, and local sediment balance (Nicholls and Cazenave 2010; Ranasinghe 2016). Although RSLR-induced erosion is a well-established hazard, quantitative assessments remain subject to uncertainty due to limitations in process understanding and model validation. Although the equilibrium-based Bruun's rule is the most used method (e.g. Le Cozannet et al. 2014), there is disagreement about its validity (e.g. Cooper and Pilkey 2004) and alternative models have been proposed (e.g. Ranasinghe et al. 2012), though all models exhibit inherent uncertainty and have been hardly validated (e.g. Le Cozannet et al. 2016). Their application also involves different sources of uncertainties (Toimil et al. 2020) and, as a consequence, no universally accepted model exists.

At the Mediterranean Basin scale, long-term shoreline retreat due to sea level rise (SLR) has been estimated using a modified version of the Bruun's rule. Median retreat projections by 2050 are −17.5 m [−27.7 to −8.8 m][34] and −23 m [−36.3 to −11.1 m] under the Representative Concentration Pathways (RCP)[35] RCP4.5 and RCP8.5 respectively *(very likely)*, increasing to −40 m [−65.1 to −20.1 m] and −65 m [−115.0 to −31.3 m] by 2100, respectively *(very likely)*. Expected RSLR-induced retreats present a spatial variability driven by local increases in RSLR, with expected larger values in subsiding areas such as major deltas, and areas with milder slope shore faces. As an example, Sharaan and Udo (2020) estimated a 66% increase in SLR-induced shoreline retreats along the Nile delta when compared to those calculated for RCP8.5. In addition to this global and consistent assessment, there are numerous local and regional assessments using different RSLR scenarios and erosion models. Among them, it is worth highlighting there are few for high-end scenarios that are relevant from a risk management perspective (Hinkel et al. 2015), such as that of Jiménez et al. (2017) for Catalonia (Spain) and that of Thiéblemont et al. (2019) for the entire European coastline. These assessments predict much larger shoreline retreats, proportional to the increase in SLR considered in such scenarios.

The combination of beach evolution rates at the different scales and their projection for the next century will result in a progressive and cumulative shoreline retreat along the entire Mediterranean coastline, with the exception of areas where local sediment budget determines the accumulation of sediment to compensate for such erosion. This, combined with current high rates of urbanisation along the Mediterranean coastline and projected urban development (Wolff et al. 2020), results in limited accommodation space along the coast. This situation favors the appearance of coastal squeeze, leading to generalised beach narrowing and, consequently, an increased likelihood of beach disappearance in the

---

[34] In the report, unless stated otherwise, square brackets [x to y] are used to provide the assessed very *likely* range, or 90% interval.

[35] Representative Concentration Pathways (RCP), as defined in IPCC AR5 are greenhouse gas concentration (not emissions) trajectories labelled by the associated radiative forcing values in the year 2100 (2.6, 4.5, 6, and 8.5 W m^{-2}), respectively and corresponding to one stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5).
See also: https://apps.ipcc.ch/glossary/

absence of adaptation measures (e.g., Jiménez et al. 2017; Vousdoukas et al. 2020).

One of the direct consequences of coastal erosion is the loss of ecosystem services (ES) provided by beaches, since habitats in coastal areas may be affected, degraded and, eventually, disappear as erosion progresses, especially due to coastal squeeze. In the Mediterranean Basin, the most comprehensive existing study is that of Paprotny et al (2021) who evaluated the effect of coastal erosion for ecosystem services on the European coast (just the northern Mediterranean coast) for RCP4.5 and RCP8.5 scenarios. They estimated a roughly 5% decline in services with respect to current conditions by 2100 under RCP8.5. The estimated risk presented high spatial variability reflecting the variability on habitat distribution and magnitude of induced erosion, the eastern Mediterranean, being the area concentrating the largest estimated declines in ecosystem services along the European Mediterranean coast.

In addition to these chronic erosion processes, the impact of storms on Mediterranean sedimentary coasts can cause major episodic erosional events, with shoreline retreats of the order of several tens of metres occurring over the duration of the event (up to a few days) (e.g. Adriatic coast: Ferrarin et al. 2020; Algier: Amarouche et al. 2020; northwestern Mediterranean: Jiménez et al. 2018). The magnitude of the induced erosion will depend on the incident storm properties (waves and surge). Since the most severe wave storm conditions are generally found in the western Mediterranean (e.g. Sartini et al. 2017), this would be the area most susceptible to experiencing larger storm-induced impacts. However, the real beach erosion will not only depend on the storm magnitude but also on the protection capacity provided by beaches and dunes (i.e. local geomorphology) in such a way that storms need to exceed a given threshold to produce a significant impact on the coast (e.g. Armaroli et al. 2012 for critical thresholds in the North Adriatic Italian coast; Gervais et al. 2012 in the Gulf of Lion French coast). The stochastic nature of storms and their large spatial variability along the Mediterranean Basin, the dependence on the geomorphology of the coast at the moment of impact, and the variety of existing models with different predictive capabilities contribute to a limited number of comprehensive storm impact assessments at the Mediterranean Basin scale. Vousdoukas et al (2020) estimated a basin-averaged storm-induced shoreline retreat of about 4 m for a 100-year return period event, with no significant climate change-induced variation by the end of the century. This estimate was derived using a simplified approach to optimise calculations along the entire world coastline and, as average value, it underestimates registered retreat recorded along the Mediterranean coastline, where observed and locally modelled values for similar return periods amounts to about 20 m or even greater (e.g. Armaroli and Duo 2018; Jiménez et al. 2018).

Future changes in the magnitude of storm-induced erosion will be determined by projected changes in wave storms along the Mediterranean. Although, as mentioned in *Chapter 2*, existing projections for different scenarios do not predict any significant increase in wave height, some new analysis of wave buoy records and hindcasts have detected an increasing trend of recorded maximum significant wave height over the last 40 years in the western Mediterranean, with some records over recent years (Amarouche et al. 2022). Also, potential changes in medicanes will modulate future risks at this scale according to the potential changes in their frequency and intensity (see *Chapter 2, Section 2.2.3*). Finally, it is important to consider that the impacts associated with coastal erosion are largely determined by existing geomorphology. As described above, medium- and long-term erosion processes will largely dominate future coastline evolution around the Mediterranean Basin. Therefore, even in the absence of changes in storm climate over the next decades, decreasing beach widths (increasing geomorphic vulnerability) and increasing development of coastal areas (increasing exposure) will lead to increased erosion risks around the Mediterranean Basin. Evidence of this trend has already been observed in the northwestern Mediterranean during the last decades of the 20th century and early 21st century in the northwestern Mediterranean (Jiménez et al. 2012).

3.2.3 Flood risks in coastal zones

Flooding in coastal zones can be simply defined as the situation in which dry land is submerged by water. Like the case of erosion, the drivers and factors that control and determine flooding are of different origin and operate at different time scales and spatial scales which leads to it being possible to identify different types of flooding. In the case of the Mediterranean coast, the most common types are floods associated with maritime storms, river floods, flash floods, pluvial floods, and those due to breakage of hydraulic infrastructure. On numerous occasions, events combining more than one type of flood occur. Given that a majority of coastal cities and towns are in flood-prone areas, and that intense rainfall is very frequent in the region, urban flooding is a problem aggravated by the growing shift of the population towards coastal locations. Often a combination of these factors worsens the situation.

3.2.3.1 Flash floods and fluvial floods

As mentioned in *Chapter 2*, the most frequent drivers of flooding in the Mediterranean coastal zone are short but heavy precipitation events usually associated with cyclonic activity. The Mediterranean coast is characterised by a marked orography that has led to the existence of numerous torrents and small basins with high slopes, in which flash floods frequently occur because of this heavy rainfall (Llasat et al. 2010; Gaume et al. 2016). In coastal towns that have grown around these torrents, the damage caused by flash floods can be very significant. In some towns the torrents are totally or partially covered, but if the drainage network is not sufficient, they can still flood. Many times, floods caused directly by rain are combined with flash floods. Consequently, disastrous flash floods are more frequent in Mediterranean coastal areas than other European regions due to local climate and topographic conditions, and the high population and urban settlements in flood-prone coastal areas (Gaume et al. 2016). Flash floods particularly impact the northwestern, eastern and southeastern coasts of the Mediterranean, but also remote areas (Gaume et al. 2016; Gohar and Kondolf 2017; Petrucci et al. 2019; del Moral et al. 2020; Faccini et al. 2021; Diakakis et al. 2023). Fluvial floods occur less frequently on the Mediterranean coast because they require more sustained heavy precipitation events, and in some regions, structural measures, such as dams have been used to reduce the potential hazard (Ward et al. 2020).

The analysis of river flooding trends can be carried out from gauging stations. The analysis by Blöschl et al. (2019) shows a decreasing trend for the Mediterranean region in medium and large basins for the period 1960–2010, mainly due to a decrease in precipitation and increased evaporation (see also *Chapter 2, Section 2.2.2*). This trend is consistent with the climate projections shown by Alfieri et al. (2015), that agree on a 30% reduction in annual precipitation in southern European countries, particularly in the Iberian Peninsula, Greece, and southern Italy, with the consequential decrease in average streamflow. In some basins, the increase in forest mass must be added to the previous explanation, mainly due to the abandonment of agricultural activity (Fader et al. 2020). Tramblay et al. (2019) shows that most trends point towards fewer annual flood occurrences above both the 95th and 99th percentiles for the majority of basins of the south of France, and particularly, on the Mediterranean French coast. These results imply that the observed flood risk increase in recent decades is mostly caused by human factors such as increased urbanisation and population growth rather than climate factors. Since most flash floods occur in ungauged catchments, trend analysis is more difficult, and is usually carried out from the episodes produced and identified by the damage they have caused. Flash flood events have increased since 1981 in coastal Mediterranean regions of Italy, France, and Spain (Llasat et al. 2013). This positive and significant trend of 2.5 floods per decade would also be justified by the increase in vulnerability and exposure in coastal areas close to the torrent or stream, despite improved coping capacities (Llasat et al. 2021a). However, some studies already show an increase in rainfall intensity on a sub-daily scale, and even on a sub-hourly scale, as well as the increase of convective precipitation in some Mediterranean regions (Llasat et al. 2021b; Treppiedi et al. 2023). The frequency of flash floods has been increasing over recent decades *(medium confidence)* for the combined effect of urban expansion in areas of fluvial pertinence and climate change, namely the interaction between anthropogenic landforms and hydro-geomorphological dynamics (Faccini et al. 2021). Land or urban mismanagement is a third concurrent factor affecting flood vulnerability (Saber et al. 2020). Added to this increase in vulnerability and exposure, heavy precipitation on a sub-daily scale shows a positive trend in recent decades *(medium confidence).* Therefore, in some regions of the northern Mediterranean, an increase in convective precipitation has already been detected (Llasat et al. 2021b; Treppiedi et al. 2023).

In the future, disastrous flash floods will *likely* become more frequent and/or intense due to climate change and the growth of urban areas *(medium* *confidence).* This fact is aligned with the increase in heavy precipitation projected by Tramblay and Somot (2018) in the northern Mediterranean for the middle of the century, and by Cortès et al. (2019) for the eastern Iberian Peninsula. These authors have projected an increase in the precipitation recorded for events exceeding 40 mm per day, which is the threshold associated with potential flash floods. If this increase in precipitation is combined with different socioeconomic scenarios, it is *likely* to raise the probability of an event causing significant economic damage.

3.2.3.2 Coastal floods

At the same scale but of marine origin, the impact of coastal storms with high waves and/or storm surges will cause the temporary inundation of the coastal zone when water levels at the shoreline exceed the elevation of the coast. This hazard, usually accompanied and exacerbated by beach and dune erosion in sedimentary coasts, is frequent along the entire Mediterranean coastline, with their magnitude depending on the local values of the total water level, the local level of protection (provided by the beach or dune in natural areas and structures on urbanised coasts) and the extension of the flood plains. Consequently, although there are different studies providing global or continental-scale extreme sea levels for both present and future climate change, existing attempts for mapping flood-prone areas at such scale have not been validated (Paprotny et al. 2019), and they need to be done at local level to have a reliable estimation of the risk (e.g. Perini et al. 2016). It should also be noted that under the European Directive on Floods, most European Mediterranean countries have produced risk maps for coastal inundation associated with different return periods.[36]

Scicchitano et al. (2021) analysed coastal flooding in Sicily under both common storms and medicanes. They found that, although they are apparently similar drivers, the risk of flooding associated with medicanes was significantly greater than that estimated for common seasonal storms, due to the higher induced storm surge. Toomey et al. (2022) characterised coastal hazards associated with medicanes and found that the highest induced waves are generated in the central and the southwest part of the western Mediterranean, while the highest surges are predominantly observed in the Adriatic Sea.

3.2.3.3 Compound events

One intrinsic characteristics of flooding in coastal areas is that it can be induced by different climate drivers, such as storm surge, run-up, rainfall, and river flow, which are often interconnected (Berghuijs et al. 2019), and may produce what is commonly referred to as compound flooding. Depending on their type, these events can amplify impacts relative to those from the same events occurring separately, or accumulate impacts at spatially distant locations (Zscheischler et al. 2020). Compound flooding has been identified in historical records of past damaging floods in Europe, especially in Italy and France (Paprotny et al. 2018). The very extreme impact of Storm Gloria in January 2020 along the Spanish Mediterranean coast drastically demonstrated their integrated impact (e.g., Amores et al. 2020; Canals Artigas and Miranda Canals 2020). From a risk perspective, these events are highly relevant, as they can significantly increase the intensity and/or the spatial and temporal extent of the impact (and associated damage). They may overwhelm the capability of emergency response services, which would be required to address a large number of simultaneous emergency situations throughout the region and/or sustain response efforts over a relatively long period.

In the analysis of these events, different drivers can be considered to contribute to compound flooding. Bevacqua et al (2019) analysed compound flooding by considering events compounded by heavy rainfall rates and high-water levels due to surge and astronomical tides. They found that the highest probability under present climate conditions is mainly concentrated along the Mediterranean coast, with the regions of the Gulf of Valencia (Spain), northwestern Algeria, the Gulf of Lion (France), southeastern Italy, the northwestern Aegean coast, southern Türkiye, and the Levante region having return periods shorter than 6 years for

---

[36] https://ec.europa.eu/environment/water/flood_risk/links.htm

compound flooding. A similar result was obtained by Camus et al. (2021), who analysed compound events involving pluvial, fluvial, and oceanographic drivers along European coasts, identifying the northern Mediterranean as a hotspot for compound flooding potential *(medium confidence).* In contrast, Couasnon et al. (2020) analysed compound flooding by combining river discharges and storm surges and found that the Mediterranean Sea did not exhibit a clear pattern in the co-occurrence of these drivers.

As an example, at a smaller scale, Sanuy et al (2021) analysed the occurrence of compound events involving heavy rainfall and storm waves on the northwestern Mediterranean coast (Catalonia, Spain). They found that the area has a high probability of experiencing compound extreme events, with an average of three events per year. However, significant variations in event characteristics were observed along the territory, despite its relatively small size (about 500 km of coastline).

Regarding the future evolution of these events, existing analyses do not provide conclusive results. According to Bevacqua et al. (2019), climate models show disagreement on the direction of future changes in the probability of compound flooding along much of the Mediterranean coast. In this context, Paprotny et al. (2020) analysed the performance of different models in predicting these events in Europe and found considerable regional differences in the strength of the dependence on surge-precipitation and surge-discharge pairs. While the models reproduce these dependencies reasonably well in northwestern Europe, their performance is less successful in the in the southern part.

3.2.3.4 SLR-induced inundation

At long-term scale, flooding in coastal zones will be driven by climate change, which can cause gradual permanent inundation due to sea level rise, and may also exacerbate storm-induced flooding events. To assess the extent and risk associated with SLR-induced inundation, the first element to be characterised is the local magnitude of RSLR along the coastal zone. In the Mediterranean, there is an increasing availability of SLR flooding scenarios, notably for sites which are particularly prone to the coupled effects of sea-level rise and negative vertical land motions such as deltas and coastal plains, which concentrate the highest risks of permanent inundation (e.g. Snoussi et al. 2008; Antonioli et al. 2017; Aucelli et al. 2017; Vecchio et al. 2019; López-Dóriga and Jiménez 2020). These studies have employer various methodologies, mainly based on the use on projections of future global sea-level rise based on various IPCC greenhouse gas emission scenarios, corrected for the local glacial isostatic adjustment (GIA) contributions. These projections are coupled with the assessment of local subsidence which can be derived from Holocene data (e.g. millennial scale), from long tidal gauges (e.g. centennial scale), GPS, or Interferometric Synthetic Aperture Radar (InSAR) data (e.g. decadal scale).

Furthermore, for future sea-level rise scenarios to be considered reliable, they must be based on high-resolution topography data, specifically Digital Elevation Models (DEMs) derived from Light Detection and Ranging (LiDAR) surveys. These LiDAR-baseed DEMs are now available for a large portion of the Mediterranean coasts and are often provided with 1 x 1 or 2 x 2 m cell width. These data have a general mean vertical resolution of about 10 to 20 cm (Anzidei et al. 2021; Rizzo et al. 2022). In contrast, scenarios based on topographic data with lower vertical accuracy should be disregarded, as the associated topographic error may represent more than 30% and more than 50% of the expected flooding under the RCP8.5 and RCP2.5 sea-level rise scenarios for the year 2100, respectively.

With respect to the flooding technique used, most of the Mediterranean Sea-level scenarios are based on a classic 'bathtub' approach in which areas below the expected sea-level elevation and hydraulically connected to the sea are delineated as being flooded (e.g. Di Paola et al. 2021). This methodology is considered suitable for urban, armoured, rocky, and passive coasts characterised by moderate wave action and reduced sediment supply. However, the 'bathtub' flooding scenarios approach may be less accurate for active sedimentary coastal areas where future sea-level rise has more dynamic effects than inundation alone (FitzGerald et al. 2008; López-Dóriga and Jiménez 2020). In this morphological context, a wide range of processes driving coastal evolution is expected to occur, which may counteract the incoming sea-level rise. To date, the dynamic responses of shorelines have rarely been included in most of the Mediterranean assessments of future sea-level scenarios.

Another important challenge in the definition of future flooding scenarios is to define a clear relationship between the inundated area and the resulting damage (López-Dóriga and Jiménez 2020). A typical approach is to consider the loss of function/habitat in the inundated area even if this often overestimates damage, especially from an environmental standpoint, as the resilience of natural areas is not always considered (Lentz et al. 2016). Presently, determining the physical and ecological responses of coastal habitats to future change remains a difficult task (López-Dóriga and Jiménez 2020). There is thus a growing need to integrate dynamic interactions between physical and ecological factors to better predict the impact scenarios of sea-level rise on low-lying coasts.

3.2.3.5 SLR-enhanced floods

It is expected that climate change and, SLR in particular, will increase extreme total water level at the shoreline (including wave runup and storm surge) and the associated flood risk (e.g. Vousdoukas et al. 2018; Kirezci et al. 2020; Almar et al. 2021). Practically, SLR will cause a decrease in return periods for given total water levels, which implies an increase in the likelihood of flood events (i.e. they will be more frequent). Alternatively, the total water level associated with a given likelihood of occurrence will be higher.

Almar et al. (2021) estimated the current variation in temporary coastal flooding by assessing the annual number of overtopping hours[37] from 1993 to 2015. They identified an increasing trend along most of the world's coastlines, with the southern Mediterranean being one of the areas experiencing the largest increase. This trend was associated with the region's small variability in extreme coastal water levels, meaning that even small increases in regional sea level can have a significant impact on overtopping. Under the RCP8.5 scenario, these authors estimated that by the end of the 21st century, the globally aggregated annual overtopping hours were projected to be up to 50 times greater than present-day levels, with more regions projected to become exposed to coastal overtopping.

In an independent study, Kirezci et al (2020) estimated that, in the absence of coastal protection or adaptation, and assuming a mean RCP8.5 SLR scenario, there will be a 48% increase of the world's land area, 52% of the global population and 46% of global assets being at risk of flooding by 2100 with respect to the current situation. The estimated increase in flood risk along the European coast has been associated with rising extreme water levels and increasing socioeconomic development of the coastal zone (Vousdoukas et al. 2018), with climate change being the main driver of the future rise in coastal flood losses. Regarding the magnitude of estimated extreme total water levels under SLR by 2100, the Mediterranean Basin is the area with the lowest predicted total water level, with the North Adriatic in Italy and the Gulf of Gabes in Tunisia being the areas with the highest water levels.

3.2.4 Tsunamis and meteotsunamis

3.2.4.1 Tsunamis

Tsunamis are unpredictable and infrequent but potentially large-impact natural disasters (see *Chapter 2, Section 2.2.9.4*). They are generated by underwater and/or coastal earthquakes, volcanic eruptions, as well as landslide processes (Papadopoulos et al. 2014). Tsunami activity, although infrequent, seriously threatens the communities along the coastal zones of the Mediterranean Basin (e.g. CIESM 2011). Tsunami sources in the Mediterranean Sea are situated in the near-field domain, meaning that the travel times of first tsunami wave arrivals do not exceed half an hour or so. This feature is extremely critical from a tsunami risk mitigation perspective.

Tsunamis in the Mediterranean Sea have often caused severe damage and loss of lives. Although they are less frequent than those of the Pacific or Indian oceans, some of them are well documented historical records, such as the M[38] > 8 earthquakes in 365 CE and 1303 near Crete, and the M > 7 earthquake in 1222 near Cyprus in the eastern Mediterranean. In the eastern Mediterranean, a devastating tsunami hit the coasts of Sicily and

---

[37] Defined as the number of hours during which the extreme coastal water level exceeds the maximum coastal elevation.

[38] Where M is the moment magnitude scale of the earthquake generating the tsunami.

Calabria in 1908 following a M > 7 earthquake in the Messina Straits (Lorito et al. 2008). More recent examples include the M6.8 Boumerdès earthquake in 2003 (Algeria), which affected the Balearic Islands, the M6.7 Kos-Bodrum earthquake in 2017 (Greece-Türkiye) in the Aegean Sea, and the M7.0 Samos earthquake in 2020 (Greece-Türkiye) in the Aegean Sea. According to Papadopoulos (2014), most of the events, and the most intense ones, in the Mediterranean have occurred in the eastern Mediterranean, resulting in a tsunami recurrence of 93 years. The Hellenic Arc is a major geotectonic structure dominating the eastern Mediterranean which produce large earthquakes and tsunamis. Respective rates in the western Mediterranean are 227 years; the Marmara Sea and the Black Sea are 500 and 1250 years.

A great deal of effort has been put into data collection in the Mediterranean for tsunami monitoring operations, utilising new observational techniques and sensors. These include deep-sea sensors including ocean bottom seismometers, tidal gauges, tsunameters, smart cables, and possibly DAS (Distributed Acoustic Sensing) technology, and high-precision coastal real-time GNSS (Global Navigation Satellite Systems) for better characterisation of the tsunami source (see Babeyko et al. 2022). These instruments have been essential to reducing the uncertainty associated with both the tsunami events themselves and their sources, in addition to the uncertainty exploration that has been achieved by tsunami simulations.

Although climate change will not alter the probability of occurrence of a tectonically-induced hazard, such as tsunamis, it will indirectly increase their potential impact and risk due to higher water levels associated with SLR, which would potentially increase the inundated surface (e.g. Li et al. 2018). Preliminary assessments of these effects in the eastern Mediterranean have indicated that risks would increase due to SLR and that this driver needs to be incorporated into future tsunami risk assessments (Yavuz et al. 2020).

3.2.4.2 Meteotsunamis

Meteotsunamis are those tsunamis induced by atmospheric processes (see *Chapter 2, Section 2.4.2.3*).

Hotspots in the Mediterranean where meteotsunamis are observed to occur regularly and where severe damage has been reported mainly include the Balearic Islands (more particularly Ciutadella harbour in Menorca Island) (Monserrat et al. 1991; Ličer et al. 2017) and the Adriatic Sea (e.g. Vela Luka, Stari Grad in Croatia: Hodžić 1979; Maramai et al. 2022), but also the Strait of Sicily (Šepić et al. 2018b), the Maltese Islands (Drago 2009), and some sites in the Black Sea (Šepić et al. 2018a; Vilibić et al. 2020). A comprehensive review of the meteotsunamis occurred on the Mediterranean and the Black Sea has been made by Vilibić et al. (2021).

Despite their undoubted risk for Mediterranean coasts, the meteotsunami hazard has only been assessed in the Mediterranean for the Adriatic and Balearic sites (e.g. Vilibić et al. 2008; Orlić et al. 2010; Šepić et al. 2016; Ličer et al. 2017), and not for other regions. No formal risk assessment has been carried out for any of the Mediterranean hotspots, even for those that are periodically affected by meteotsunamis.

In spite of the great efforts invested in the development of the meteotsunami warning systems, the results are still not satisfactory, leading to a loss of trust in the early warning systems. The forecasts are known to be wrong, especially when it comes to estimating the strength and destructiveness of the event *(very low confidence)* (Jansà and Ramis 2021).

3.2.5 Scarcity of suitable water resources

3.2.5.1 Freshwater resources risks; saltwater intrusion

The magnitude of the risk for coastal water resources is the result of the balance between water demands and existing resources. The recent historical climatology in the Mediterranean coastal areas explains the existence of important water demands in these areas, which tend to have a high seasonality (Niavis and Kallioras 2021). These demands are due to the existence of large populations, as well as intensive and highly productive agricultural and/or major industrial activities (Renau-Pruñonosa et al. 2016). The very important Mediterranean tourism sector (the Mediterranean zone is the top tourist destination in the world; World Tourism Organization 2018) and irrigated agriculture produce clear demand peaks during summer and will grow even more in the future, stressing water availability during these periods (Toth et al. 2018). Therefore, supplying water demand in these coastal areas with significant urban, agricultural and/or industrial development, and scarce water resources is a challenging issue (Zouahri et al. 2015), especially during droughts and, even more critically, during the summer due to tourism demand, which might be exacerbated in the future due to climate change (Tramblay et al. 2020). Global warming scenarios predict an increase in irrigation demands alongside population growth, especially in the coastal areas of eastern and southern Mediterranean countries, leading to higher water demands and further deterioration of water quality (Cramer et al. 2018).

In many areas along the Mediterranean coast, surface water resources are scarce or intermittent, which forces demand to be partially or fully supplied using groundwater resources (Sola et al. 2013). Preserving water quality in these water bodies, which also influence water availability for different water uses, is a challenging issue. In addition to the traditional water quality risks that exist in inland systems (e.g. nitrate and pesticide pollution, urban and industrial discharges, emerging contaminants, etc.) the issue of salinity from seawater intrusion also needs to be addressed (Custodio 2017). Considering that aquifers are the main source of water supply in many Mediterranean countries (Leduc et al. 2017), there has been a certain degree of over-pumping, especially during summer and drought periods. It has led to salinisation processes with seawater progressing into coastal aquifers (Rosenthal et al. 1992). In general, the Mediterranean areas with higher risks from extreme hydrological events (droughts and floods) are located in coastal areas (Fader et al. 2020). The most frequent and severe droughts are usually observed near the coast (Gomez-Gomez et al. 2022). Many aquifers of the EU Mediterranean coastline in Italy, Spain and Türkiye have suffered historically from saltwater intrusion *(Figure 3.2a)* (EEA 2009). For example, in Spain, 56 of the 95 identified coastal groundwater bodies have been affected by seawater intrusion processes (Custodio 2017). Intrusion is also very relevant across Greece, where it is estimated that the total surface area of aquifers impacted by seawater intrusion is about 1500 km^2 (Daskalaki and Voudouris 2008). The North African coast of the Mediterranean is also extensively affected by seawater intrusion *(Figure 3.2b)*. Significant saltwater intrusion is observed in the Nile Delta in Egypt (Sefelnasr and Sherif 2014), in Morocco coastal areas (Khouakhi et al. 2015), Tunisia (Agoubi 2021) and in Jeffara plain, Libya (CEDARE 2014).

Regarding the future evolution of freshwater resources, the availability of conventional freshwater resources for the different uses is expected to decrease and be degraded, especially in the southern and eastern Mediterranean *(high confidence)*. The increase in water demand and in the frequency and severity of droughts, the reduction of freshwater recharge, and the effect of sea level rise will lead to an increase in seawater intrusion in coastal aquifers (Pulido-Velazquez et al. 2018; Tramblay et al. 2020).

The unconventional water resources generated by desalination in the Middle East and North Africa will reduce the risk of water scarcity, but it will increase the risks of environmental impacts, especially on near-coastal marine ecosystems, energy requirements and associated CO_2 emissions *(high confidence)*.

3.2.6 Coastal pollution risks

In the Mediterranean Basin, coastal and estuarine waters and their ecosystems have long been under the pressure of land-based pollution, which is increasingly exacerbated by climate change impacts at present. Combined effects of pollution and climate change influence coastal water quality and

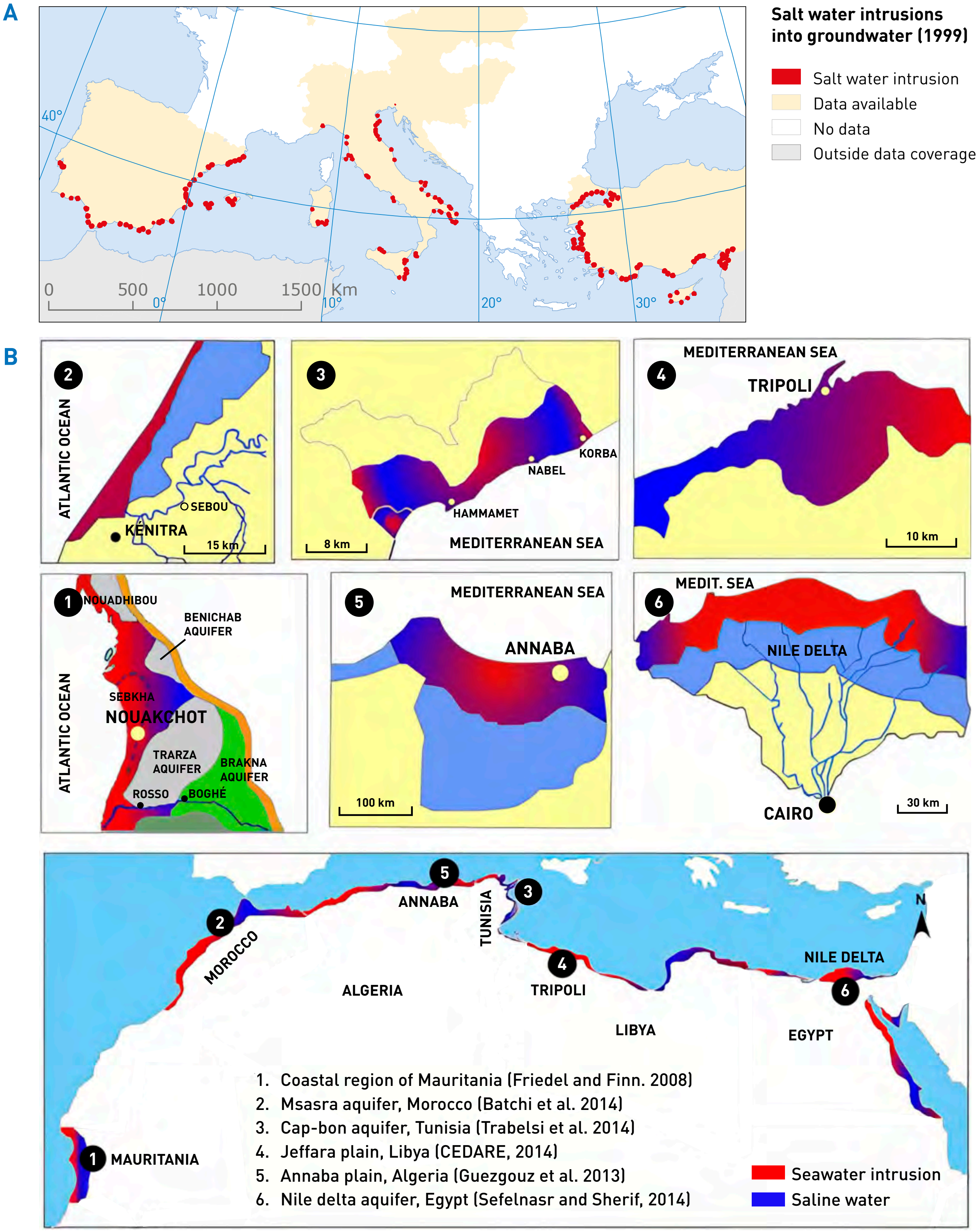


Figure 3.2 | Historical and current saltwater intrusions into groundwater in Europe and North Africa. A) Map of historical saltwater intrusions into groundwater in Europe in 1999 as a result of groundwater over-exploitation. Source: EEA (2009). B) Maps of seawater intrusion in North Africa. Source: Agoubi (2021).

ecosystem health, and trigger habitat changes and losses. Furthermore, pollution build-up on coastal ecosystems affects human health via the food chain. Coastal water pollution may be of various physical, chemical or biological origin whilst others are toxic, persistent, and emerging and may also have transboundary impacts. The combined effect of human-induced pollution and climate change pose severe risks on ecosystems and human health *(high confidence).*

Littoralisation[39] together with heavy urbanisation in Mediterranean coastal areas have increased water quality risks. Consequently, coastal waters suffer from pollution risks generated by diverse pollutants. Marine pollution stems from a wide diversity source comprising physical, chemical and biological origins that create harmful effects on ecological systems. These adverse impacts on natural systems might be generated due to various anthropogenic activities that bring several substances/materials into coastal waters. If they exceed certain threshold values, these substances are *very likely* to become harmful and have detrimental effects on the biological components of coastal ecosystems (Beiras 2018). In addition to organic pollution, other pollutants of various origins exist, some of which are toxic and persistent, such as POPs, whose origins can now be identified. Their threshold values are regulated by the Stockholm Convention[40]. Others are micro-pollutants whose components are also of various origins (e.g. pharmaceuticals and personal care products (PPCPs), microplastics), which are emerging.

Accumulated pollution from various sources in coastal and bathing waters endangers human health as well as the health of coastal ecosystems because the magnitude of anthropogenic impacts has been higher in coastal waters compared to offshore waters with increasing pressure due to climate change, overfishing and pollution as prevailing pressures (Halpern et al. 2008; Díaz et al. 2019).

An overview of nutrients, metals, emerging pollutants, persistent organic pollutants, and major environmental changes due to climate change and their impacts on coastal ecosystems will help understand the synergistic effects of climate change and marine pollution. Researchers have revealed that the interplay between environmental effects and impact caused by multiple stressors both from natural and anthropogenic sources result in synergistic effects. However, interactions among multiple stressors in marine environments may be synergistic or antagonistic. These interactions among multiple stressors vary with stressor intensity, exposure duration and biological response. Recent findings suggest that synergisms are predominant under multiple stressors because increased stressor intensity is *likely* to overcome compensatory mechanisms (Harley et al. 2006; Crain et al. 2008; Park et al. 2014; Przeslawski et al. 2015; Gunderson et al. 2016; R. Lange and Marshall 2017).

3.2.6.1 Nutrients

Eutrophication caused by excessive land-based nutrient inputs has affected many areas in the coastal zone (see *Chapter 2, Section 2.4*). Coastal eutrophication, which is caused by seawater being enriched with mainly nitrogen and phosphorus, has significantly increased within recent decades in the semi-enclosed parts of the Mediterranean in particular (Danovaro et al. 2009; Cabral et al. 2019; UNEP/MAP 2023). This phenomenon has a widespread impact on ecosystems by promoting various negative effects including hypoxia or anoxia, episodes of massive mucilage formation, harmful algal blooms (HABs), and acidification.

The most detrimental negative effect is usually hypoxia, which represents concentrations of dissolved oxygen lower than 2 mg L^{-1}, the threshold value for living organisms (Crain et al. 2008; Howarth 2008). Similarly, another harmful effect may be generated by toxic HABs which may cause human illness and even mortality. They also have socio-economic impacts related to toxicity of harvested fish and shellfish, loss of aesthetic value of coastal zones, and reduced bathing water quality impacting the tourism activities of coastal areas around the Mediterranean Basin.

---

[39] Littoralisation is defined by the United Nations in CCD Annex IV for the Northern Mediterranean as the process of concentration of population, settlements along with economic activities in coastal areas: https://www.unccd.int/convention/regions/annex-iv-northern-mediterranean

[40] https://chm.pops.int/TheConvention/Overview/TextoftheConvention/tabid/2232/Default.aspx

Coastal eutrophication is of medium or important significance in 13 Mediterranean countries (Table 3.4 in Fader et al. 2020).

3.2.6.2 Metal pollution

Estuaries function as long-term repositories and sinks for historical metal contamination, driven by the strong particle reactivity of metals with sediments (e.g. Golden Horn estuary in Istanbul, Türkiye, Acheloos River estuary, Greece) (Ridgway and Shimmield 2002; El-Amier et al. 2021; Zeki et al. 2021). Although biological processes require certain metals that are essential for biochemical reactions, some metals are not metabolised, but in both cases, high toxicity may occur even at low concentrations. The toxic effects of metal exposure include increased energy demand, which impacts the metabolic structure and growth of marine ecosystems (Richir and Gobert 2016; Yilmaz et al. 2017 2018). The toxic effect of metals may also cause significant immunosuppression or cause impaired reproduction and/or development (Rainbow 2002).

Benthic fish are prone to bioaccumulate heavy metals like cadmium and mercury, reflecting the contamination status of the marine environment by heavy caused mainly by industrial pollution. Heavy metals and pesticides cause toxicity and various diseases in fish due to aquatic pollution (Islam et al. 2018; Rani et al. 2022). Environmental assessment studies have been largely conducted in polluted areas affected by industries and ports activities. For example, several research studies conducted in Portman Bay (Spain) have shown that metal pollution from industrial and urban dumping has impacted the marine ecosystem. In this context, fish accumulate metals through ingestion of particulate material suspended in the water, food ingestion, ion-exchange with dissolved metals, and adsorption by tissue and membrane surfaces (Ben Hamed et al. 2017).

Since trace metals are not degradable, they accumulate in marine organisms throughout food webs (Vareda et al. 2019). Mercury bioaccumulation in marine food webs is a representative example of this issue (Fonseca et al. 2019), as mercury exposure has been shown to causes severe neurotoxic effects in marine fauna and humans (Depew et al. 2012; Karagas et al. 2012). Although trace metal abatement measures in the marine environment have improved in recent decades in parallel with the enforcement of the EU Directives, mercury pollution remains a global issue due to its persistence and, most importantly its capacity for long-distance transport in the environment, which can lead to transboundary pollution.

3.2.6.3 Persistent Organic Pollutants (POPs)

POPs can travel long distances in the aquatic environment and tend to accumulate in sediments due to their strong particle association associated with their hydrophobic properties. Contaminated sediments represent a significant threat to associated biota and to other organisms via the marine food web (e.g. demersal fish and marine birds). Furthermore, sea level rise and seawater intrusion in coastal aquifers may cause POPs present in coastal waters to contaminate these aquifers, compromising the quality of freshwater resources.

Across the Mediterranean Basin, pollution is transboundary, ubiquitous, diverse and increasing in both quantity and variety of pollutants, due to intensified domestic, industrial, and agricultural activities, as well as climate change *(high confidence)* (see Cherif et al. 2020, *Section 2.3.1*).

Persistent organic pollutants (POPs) pose a serious concern for transboundary pollution as their transmission can be long distances away from their sources, since they are not biodegradable in water but in fatty acids of living organisms and can enter the marine food web (Fader et al. 2020). Therefore, the synergistic effects of climate change and coastal water pollution may result in transboundary water pollution affecting even terrestrial coastal systems such as coastal aquifers and coastal ecosystems located at long range from the source of pollution.

The synergistic effects of climate change and coastal pollution are shown on *Figure 3.3* (Cabral et al. 2019).

Furthermore, interactions among multiple stressors in marine environments may be synergistic or antagonistic. These interactions among multiple stressors vary with stressor intensity, exposure duration and biological response. For instance, recent research shows that the individual and combined effect of three common water quality stressors on marine diatoms depend on additive, antagonistic or synergistic interactions (King et al. 2022).

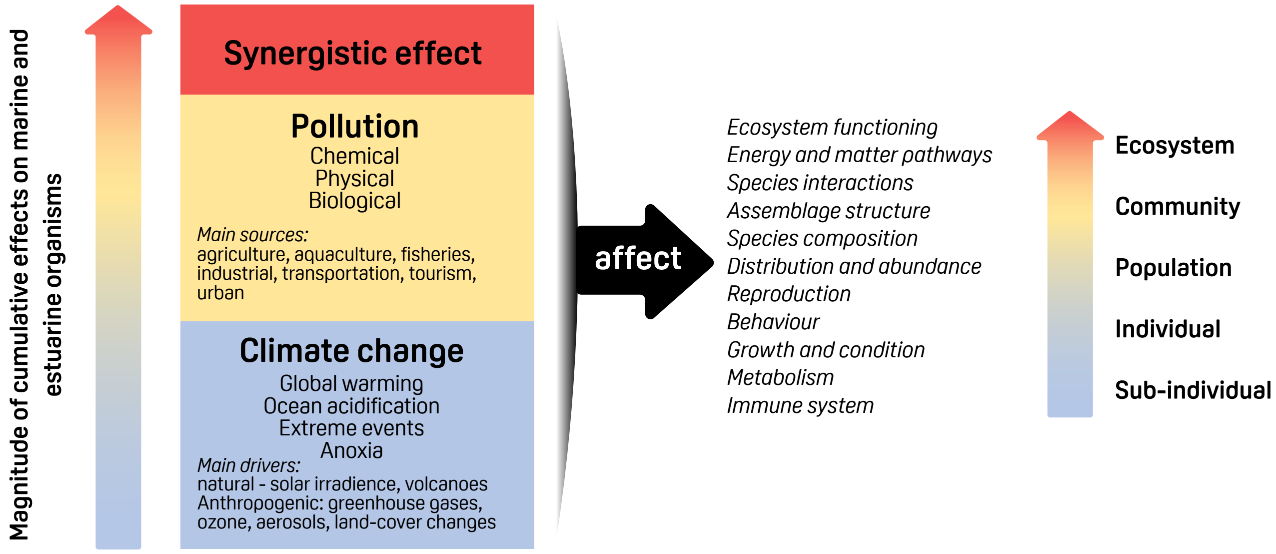


Figure 3.3 | Synergistic effect of climate change and coastal pollution. Source: Cabral et al. (2019).

POPs may create increased impact on the marine organisms, if microplastic pollution (MPs) exists in the same environment, because MPs, due to their high sorption ability for POPs (e.g. polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCPs)), generate direct or indirect toxicity in marine organisms, ecosystems, as well as humans. Beaches are considered as the ecosystems most affected by MP pollution, therefore, indirectly by POPs since the ubiquitous feature of POPs on the one hand, and the pervasiveness of the MPs on the other, generate combined toxicity impacts on the marine environment (Barhoumi et al. 2023).

3.2.6.4 Microplastics

Field surveys have been conducted to evaluate the threat posed by plastic pollution to the coastal and marine ecosystems of the Mediterranean (Jambeck et al. 2015; Geyer et al. 2017; Compa et al. 2019).

With the high production and consumption of plastics worldwide, the marine environment has been suffering from plastic dispersion and deposition at all levels (i.e. coastal waters, offshore, sediment). Similarly, Mediterranean marine biodiversity is at high risk of plastic exposure (Compa et al. 2019). In addition to their continuous release into the environment, plastics disintegrate into smaller pieces and disperse into nature, undergoing various physical and chemical processes. Some of the principal sources of plastics include marine litter, which is brought into coastal zones primarily by river discharge and ships (Löhr et al. 2017). High concentrations of plastics, including tiny plastic items, could have considerable environmental, health, and economic impacts (Pedrotti et al. 2016). The worst impacted regions are coastal areas, which are hotspots for plastic ingestion, and the Mediterranean coastal area is no exception (Compa et al. 2019). Plastic ingestion affects the gastrointestinal system of marine species, from invertebrates to mammals, across both demersal and pelagic ecosystems (M. L. Taylor et al. 2016). Analyses of plastic exposure show that marine species with larger home ranges are more at risk of exposure due to covering longer distances, while local species are more *likely* to be exposed to plastic closer to their home range areas (Compa et al. 2019).

Fossi et al. (2017) suggested that a risk assessment of plastic pollution across the entire Mediterranean Basin will help gather data sets to better understand the species under exposure and/or threat, as well as identify hotspot risk locations. It should be noted that the existing threat is quite difficult to assess due to the varying ecological requirements of multiple species. Compa et al. (2019) identified hotspots at risk of plastic ingestion across multiple taxa in the Mediterranean Sea, highlighting that coastal species

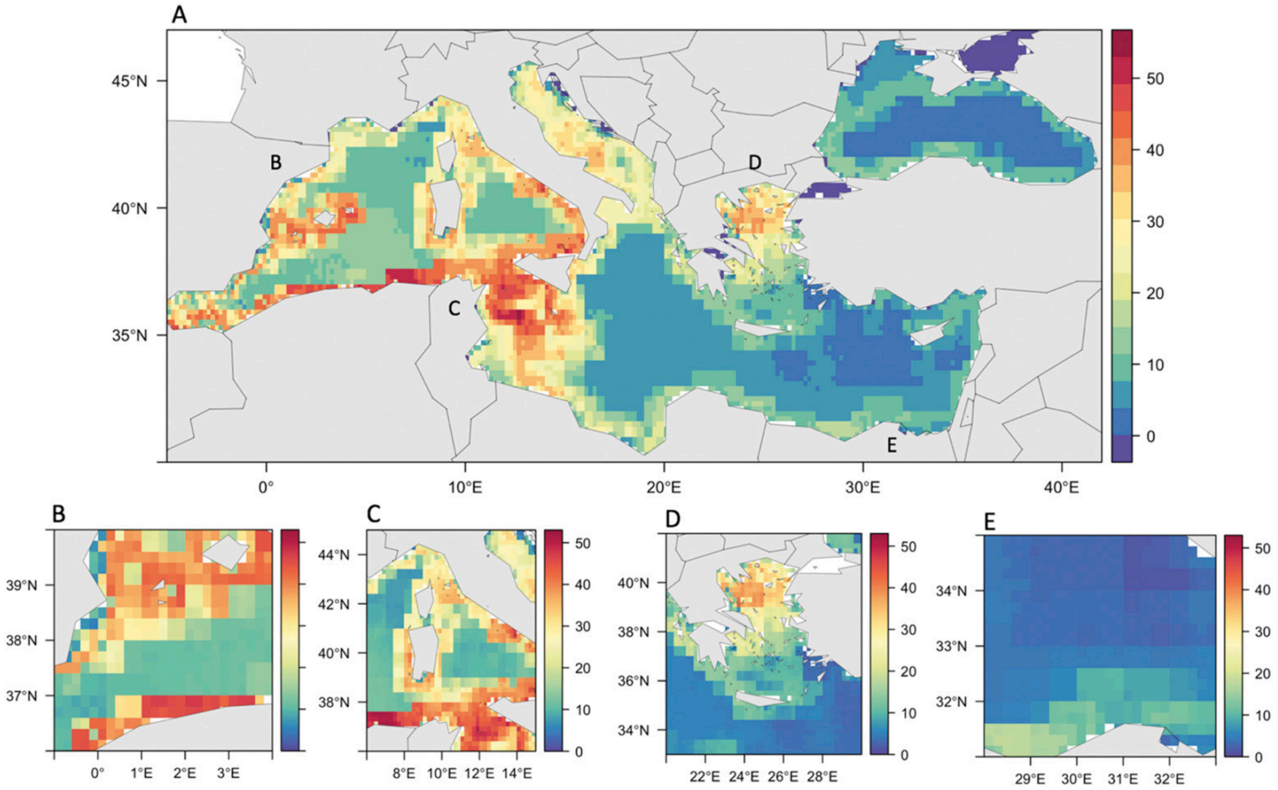


Figure 3.4 | Plastic ingestion risk across the Mediterranean Sea. A) Overall risk of predicted plastic ingestion for the 84 species modeled based on the best-fit GAM model incorporating motility, habitat, body size, and class. Red indicates high-risk areas and blue areas of low-risk of plastic ingestion in the marine diversity. Hotspot areas of plastic ingestion risk of the marine diversity for: B) coastal areas of the Strait of Gibraltar and surrounding countries, C) the Pelagos Sanctuary and the northern coast of Africa, D) Aegean Sea and E) the northern coastal areas of the south-eastern Mediterranean Sea. Source: Compa et al. (2019).

are at higher risk of ingesting plastic in the marine environment than open-sea species, as shown on *Figure 3.4.* However, the impact of plastic pollution on different seabirds and sea turtles suggests that the risks are not limited to coastal areas but may expand further to the high sea locations (Schuyler et al. 2016). The cumulative quantity of plastic waste to enter the Mediterranean Sea from land is predicted to increase by an order of magnitude by 2025 (Jambeck et al. 2015) *(high confidence)* if appropriate waste management infrastructure is not made operational.

3.2.6.5 Emerging Pollutants, pharmaceuticals, and personal care products (PPCPs)

Pharmaceutical residuals can be found in surface waters, coastal waters of heavily populated settlements, and in drinking water samples in Europe (López-Serna et al. 2013; H. Chen et al. 2018; L. Yang et al. 2020). These substances may present acute or chronic toxicity risks for aquatic organisms in coastal waters. In addition to their toxic effect, some of them are endocrine disruptors (EDCs) (Esplugas et al. 2007). Therefore, PPCPs exhibit hazardous effects due to their continuous discharge (treated or untreated) into coastal waters via wastewater treatment plants which are unable to treat them through conventional processes. Environmental health concerns stem mainly from long-term exposure to these substances, whether they are persistent or not because long-term exposure should also be considered as pseudo-persistence (Daughton and Ternes 1999; Korkmaz et al. 2022).

Several recent studies have investigated the environmental risk assessment of pharmaceuticals in coastal waters (Corcoll et al. 2014; Chaves et al. 2020; L. Yang et al. 2020; Navon et al. 2020; Dehm et al. 2021; Sadutto et al. 2021; Korkmaz et al. 2022). Based on the risk assessment results carried out in the marine environment, the following pharmaceuticals namely naproxen, diclofenac,

clofibric acid, gemfibrozil, 17ß-estradiol, and 17α-ethynylestradiol have been identified as posing high risks to aquatic organisms, and consequently to human health via the food chain. These findings emphasise the critical importance of monitoring these contaminants in the marine environment to protect the ecosystem and therefore human health (Korkmaz et al. 2022).

In addition, organic waste and antibiotics input into the marine environment via aquaculture is another pollution risk on coastal waters since feed waste excess and antibiotics that are partly metabolised by fish accumulate on the bottom of the sea floor. Feed waste and antibiotics deposition in the sediment and their accumulation in the wild fauna threatens the health of marine ecosystems due to the change in the chemical conditions of the sediment, thus affecting marine biodiversity. Studies identified that feed waste and antibiotics significantly reduce the biodiversity and abundance of benthic invertebrates (Björklund et al. 1990; Grigorakis and Rigos 2011; Liu et al. 2017; Neofitou et al. 2020; González-Gaya et al. 2022). In Murcia, Spain, it has been identified that fish feed waste from aquaculture alters the habitat and biodiversity of the benthic ecosystems in the Mediterranean Sea, whilst antibiotic residuals have additive effects to the enrichment of bacterial genes (González-Gaya et al. 2022). In addition, antibiotics may create antibiotic resistance genes in the marine environment neighbouring fish cage farms, thus threatening the effectiveness of antibiotic classes of high relevance for human medicine (H. Chen et al. 2018; Higuera-Llantén et al. 2018).

Similarly, researchers pointed out that among the emerging pollutants, caffeine poses a considerable risk whereas tramadol may also have adverse effects at high concentrations. However, results indicated that the mixture of contaminants represents a potential risk for most sensitive organisms. Researchers advise the importance of examining the mixture of contaminants to carry out proper environmental risk assessments (Sadutto et al. 2021).

3.2.6.6 Atmospheric pollution

Atmospheric pollution poses a significant risk to human health and marine ecosystems (Linares et al. 2020b; MedECC 2020b; UNEP/MAP and Plan Bleu 2020; Carreño and Lloret 2021).

Atmospheric deposition settling at sea is a source of pollution that contribute to ocean acidification, which has severe impacts on a wide diversity of marine organisms including corals, planktonic organisms, and calcifying organism structures, resulting in their degradation and mortality. Several studies in the Mediterranean have been initiated by research institutions, particularly in the eastern Mediterranean (the Levant Sea), to monitor the evolution of acidification and assess its impact on marine food webs (Lacoue-Labarthe et al. 2016).

Atmospheric pollution in coastal areas elevates the risk of respiratory and other health issues for a large number of the Mediterranean coastal population due to exposure to concentrations higher than WHO Air Quality Guideline (AGQ, WHO 2021). Although regulations are projected to reduce premature mortality from $PM_{2.5}$ by up to 55% in the EU-27 by 2030[41] (compared to 2005 levels between 340,000 and 480,000), significant portions of the Mediterranean population remain exposed to harmful pollution levels (e.g. Gómez-Losada and Pires 2020; Rovira et al. 2020; Osipov et al. 2022).

In addition, atmospheric poses a risk cultural heritage, as many UNESCO World Heritage sites in the region remain vulnerable to material degradation due to continued exposure to harmful pollutants (Spezzano 2021).

3.2.6.7 Oil spill pollution

Oil spills from refinery and maritime accidents can be the source of very serious oil pollution which affects the marine and coastal ecosystem for several years and has severe impacts on human and environmental health which translates into significant economic losses (Ülker and Baltaoğlu 2018; Ülker et al. 2022). In addition, offshore oil drilling, extraction and exploration enhances the potential of oil spills which damage marine ecosystems with hydrocarbon toxicity (El-Magd et al. 2021). Beaches and recreational areas may be destroyed or degraded by oil pollution and may further cause alterations of the ecosystem by affecting and modifying the marine habitat. The impact of petroleum toxicity causes marine organisms to be injured or killed by being covered with insoluble petroleum compounds, sublittoral organisms to be poisoned, beach flora to be destroyed by oil, and benzene, toluene, and naphthalene to bioaccumulate in marine flora, fauna, and marine life in general, causing hazardous effects on human consumption (Doğan and Burak 2007).

3.2.6.8 Final remarks and research gaps

Coastal pollution presents increasing risks for coastal ecosystem health and consequently environmental health due to the build-up effects of pollution load which is exceeding the assimilation capacity of the receiving media and due to emerging pollutants, with some of the compounds still difficult to detect and monitor. Moreover, all emerging compounds in these pollutants (e.g. PPCPs) and/or micro-pollutants (e.g. micro-plastics) can be ingested by marine species and can be home to various harmful microorganisms including pathogenic species (e.g. bacteria and viruses).

Recent research has identified that interactions among multiple stressors in marine environments may be synergistic or antagonistic. Findings suggest that an overview of pollutants of various origin and major environmental changes due to climate change and their impacts on coastal ecosystems will help understand the synergistic effects of climate change and marine pollution.

Similarly, risk assessment of plastic pollution across the Mediterranean Basin can generate valuable datasets to better understand the species at risk and pinpoint hotspots. In addition, monitoring the fate of emerging pollutants and their impact on coastal ecosystems and human health will help raise awareness, so that relevant standards to preserve both natural and human health can be monitored and enforced.

3.2.7 Risks of biological origin

3.2.7.1 Non-indigenous species

Non-indigenous species, regardless of their origin, are producing a variety of ecological and socio-economic impacts on the Mediterranean (Katsanevakis et al.

---

[41] https://environment.ec.europa.eu/topics/air_en

2014; Azzurro et al. 2022). Most of these species have been reported to affect multiple native species through a variety of mechanisms, such as predation (Gueroun et al. 2020; Prado et al. 2022), competition for resources (Caiola and Sostoa 2005; Marras et al. 2015), food web shifts (Finenko et al. 2003; Piscart et al. 2011), and vectors of pathogens or parasites (Roy et al. 2017; Peyton et al. 2019). In many cases, they also impact keystone species or species of high conservation value (Caiola and Sostoa 2005; Prado et al. 2022). However, both native and non-native (non-indigenous) species can affect species extinction and lead to serious threats to the continued health of ecosystems (Blackburn et al. 2019).

There are many examples of non-indigenous species that modify ecosystem processes or wider ecosystem functions in the Mediterranean region (Pancucci-Papadopoulou et al. 2012; Rilov et al. 2019). Extreme examples are species that behave as ecosystem engineers, that is to say that modify, create or define habitats by altering physical or chemical properties of the habitat(s) (Wallentinus and Nyberg 2007; Berke 2010). Furthermore, the lack of certain predator species can be a cause for 'eruptions' of non-indigenous species. For example, 77 species of fish are known to be predators of certain mussels (Dreissena species). However, as these fish are reduced in number and dispersion, predation of this invasive species decreases as well. The relative absence of a diverse range of native enemies (mainly predators and parasites) in newly invaded regions contributes to the rapid population growth of the invasive species (Karatayev et al. 2015).

In addition to the mentioned impacts on native biodiversity, invasive non-indigenous species negatively affect coastal ecosystem services

Table 3.1 | List, type, and description of marine ecosystem services. Adapted from Liquete et al. (2013).

PROVISIONAL SERVICES
Food: Provision of biomass (fishery and aquaculture) from the marine environment for human consumption
REGULATING AND MAINTENANCE SERVICES
Water purification: Biochemical and physicochemical processes involved in the removal of waste and pollutants from the aquatic environment
Air quality: Regulation of air pollutant concentrations in the lower atmosphere
Coastal protection: Natural protection of the coastal zone against inundation and erosion from waves, storms or sea level rise
Climate regulation: Carbon sequestration
Weather regulation: Influence on local weather conditions (e.g. influence of coastal vegetation on air moisture and temperature)
Ocean nourishment: Natural cycling processes leading to the availability of nutrients and organic matter
Lifecycle maintenance: Maintenance of key habitats that act as nurseries, spawning areas or migratory routes.
Biological regulation: Biological control of pests and invasive species
REGULATING AND MAINTENANCE SERVICES
Symbolic and aesthetic values: Senses and emotions heightened by seascapes, habitats or species
Recreation and tourism: Opportunities for relaxation and entertainment (e.g. bathing, sunbathing, snorkelling, scuba diving, sailing, recreational fishing, whale watching).
Cognitive effects: Inspiration for arts and applications, material for research and education, information and awareness

(Katsanevakis et al. 2014; Galil et al. 2017). There is strong evidence that most of the services provided by Mediterranean marine ecosystems are affected by them (Balzan et al. 2020; Dimitriadis et al. 2021; Kleitou et al. 2022; Tsirintanis et al. 2022). The most affected services are those related to food provision, but regulating and maintenance and cultural benefits are also impacted *(Table 3.1).*

As already mentioned, and according to Katsanevakis et al. (2014), food provision is the ecosystem service that has been impacted by the highest number of invasive non-indigenous species. The most cited examples of this impact are the negative effect on fisheries resources (Prado et al. 2020; Kleitou et al. 2022). Following food provision, the ecosystem services that have been most negatively affected by species are ocean nourishment, cultural services in general, and lifecycle maintenance (Katsanevakis et al. 2016, 2023).

Harmful algal blooms caused by non-native species negatively impact food and water provision (Marampouti et al. 2021). Furthermore, their impact on water resources can be exacerbated by climate change effects that will cause water shortages in some Mediterranean regions; blooms may even affect desalination, or at least increase the cost of it. There is also evidence of invasive non-indigenous species' impacts on water purification (see Salomidi et al. 2012).

Native phanerogam species and some bivalves potentially deliver coastal protection services, which are quite important under climate change scenarios with significant sea level rise and the increase in magnitude and frequency of storm surges (Ibáñez and Caiola 2021). Invasive non-indigenous species affecting these indigenous species (Prado et al. 2020, 2022; Houngnandan et al. 2022) will potentially impact coastal protection services.

Mediterranean seagrasses are potential carbon sinks and therefore provide weather regulation services. Thus, invasive aquatic vegetation that competes with native seagrasses can potentially negatively impact this ecosystem service (Silva et al. 2009). No or negligible impacts has been documented for air quality regulation and biological regulation services (Katsanevakis et al. 2014).

3.2.7.2 Mass mortalities

Mass mortality events (MMEs) have progressively increased in the Mediterranean Sea, and they have been attributed to the increase in frequency and intensity of marine heat waves (MHWs) (Diaz-Almela et al. 2007; Rivetti et al. 2014; Garrabou et al. 2022; Estaque et al. 2023) and pathogen infections *(high confidence)* (Vezzulli et al. 2010; Vázquez-Luis et al. 2017), *(Figure 3.5).* MMEs have been reported for organisms with reduced mobility, such as gorgonian corals (Estaque et al. 2023), sea grass (Diaz-Almela et al. 2007), and pen shells (Vázquez-Luis et al. 2017). In decreasing order, cnidaria, porifera, mollusca, bryozoa and echinodermata are the most affected phylums from MMEs *(high confidence)* on Mediterranean coasts (Garrabou et al. 2019, 2022).

Although the eastern Mediterranean is warming faster (Garrabou et al. 2019) and has many species living to their thermal tolerance limits, MMEs were mainly documented on the western Mediterranean coasts due to the extensive and long-term sampling efforts in favour of the west *(high confidence)* (Garrabou et al. 2019, 2022). The frequency and intensity of MMEs will *likely* increase in the future in parallel with rising MHWs *(high confidence).*

3.2.7.3 Jellyfish blooms

Jellyfish blooms, particularly those of the species *Pelagia noctiluca*, became increasingly evident in the 1980s. Not only these outbreaks were ecologically concerning but also presented immediate socio-economic repercussions (UNEP/MAP 1991; CIESM 2011). For tourists and local fishers, the presence of these jellyfish was more than just an inconvenience. Their stinging tentacles caused painful injuries, leading to direct implications for tourism, a significant industry for many Mediterranean nations. Beach tourists were often hesitant to swim in infested waters, and fishers found their catches compromised either by stings or by the presence of jellyfish in their nets (De Donno et al. 2014). Chelsky et al. (2016) emphasise that the massive abundance of jellyfish is not just an ecological concern but a substantial threat to coastal activities. This goes beyond the direct injuries caused to humans. Jellyfish blooms can impact power plants by clogging cooling water intakes, thereby causing operational challenges and monetary losses. Additionally, the post-mortem accumulation of jellyfish on shores results in beach fouling, leading to clean-up costs and a decline in beach aesthetics, further affecting tourism (Ghermandi et al. 2015).

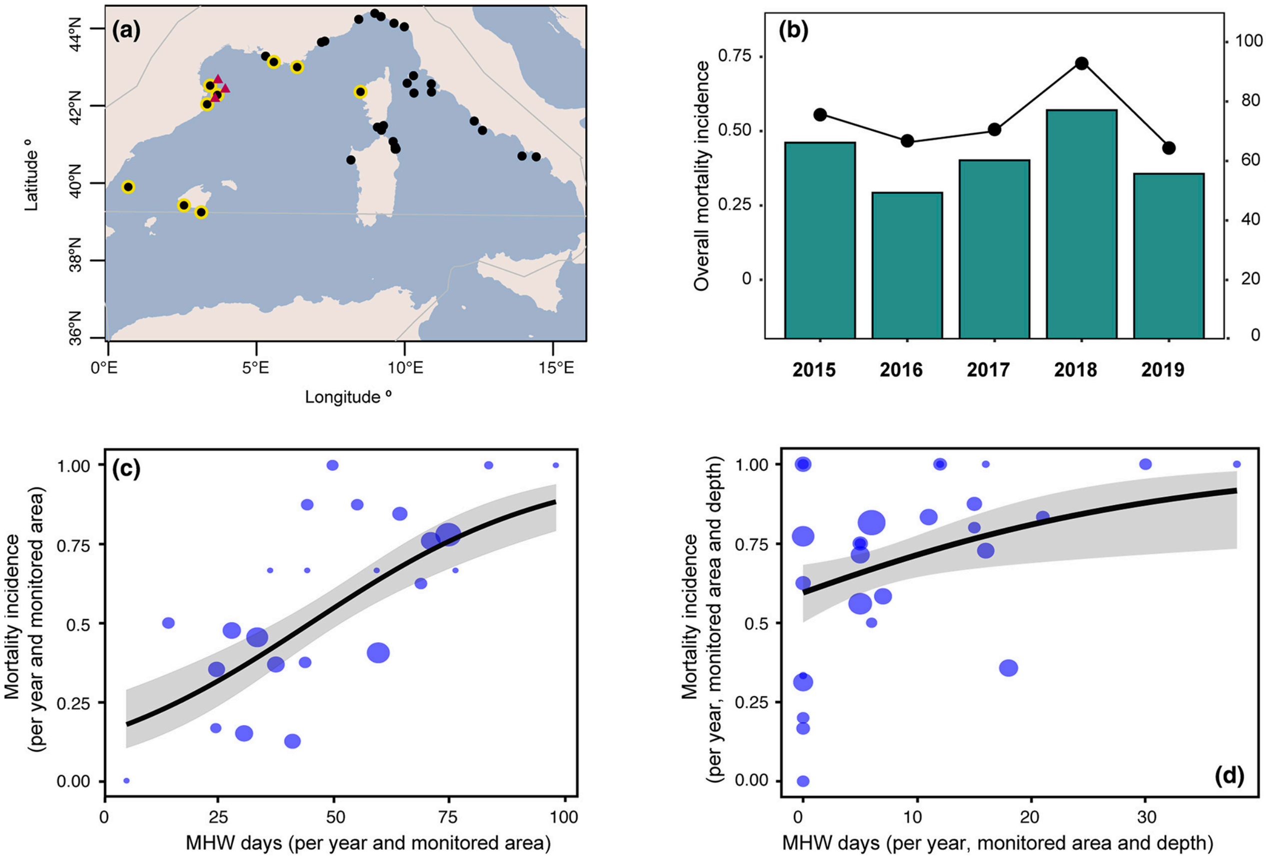


Figure 3.5 | Relationship between heat exposure (marine heatwave [MHW] days) and mortality incidence in the Northwestern Mediterranean ecoregion during 2015–2019. (a) Map of the northwestern Mediterranean ecoregion showing the location of the monitored areas included in the analysis; black dots: monitored areas used in the regional analysis shown in panel b), yellow dots : the monitoring areas considered for the analysis shown in panel c), red triangles: areas with long-term, in situ temperature monitoring used for the in-depth analysis shown in panel d); (b) Bars and points show, respectively, the yearly mean number of MHW days and mortality incidence (proportion of records showing mortality) observed across the northwestern Mediterranean basin. Panels c and d show respectively the relationship between heat exposure (yearly average of MHW days during the JJASON period) at the surface (sea surface temperature) or across depth (from 5 to 40 m) and the corresponding mortality incidence in the studied monitored areas, years, and/or depths. The lines show the predicted values of the generalized linear models and their confidence interval (95%). The size of the points is proportional to the sampling size. The map lines in panel (a) delineate study areas and do not necessarily depict accepted national boundaries. Source: Garrabou et al. (2022).

A more insidious concern associated with jellyfish blooms is the potential public health risk they pose. Jellyfish can act as vectors for bacterial pathogens, which can severely impact fish aquaculture. These pathogens, when introduced into aquaculture settings, can cause diseases among farmed fish, leading to economic losses and potential health risks if contaminated fish are consumed (Delannoy et al. 2011). Basso et al. (2019) further highlights the risks associated with jellyfish and bacterial pathogens, emphasising the need for comprehensive strategies to monitor and manage jellyfish blooms in order to safeguard both marine ecosystems and human health.

From an ecological standpoint, the proliferation of jellyfish poses significant challenges to marine biodiversity. Jellyfish are highly effective predators and compete aggressively for resources. Their burgeoning populations can deplete the availability of zooplankton, which has cascading impacts on the food web. Predatory fish that rely on smaller organisms for food can face scarcity, leading to overall reduced fish stocks (Purcell 2012; Báez et al. 2022). This not only affects the marine ecosystem but also the fishing industry, which is pivotal to many Mediterranean economies.

3.2.7.4 Mucilage

Mucilage is a dense and highly viscous substance made up of extracellular polysaccharides produced and secreted by the overgrowth of various aquatic species. Rising ocean temperatures, as well as human-induced stressors such as insufficient treatment levels and overfishing, are common causes of such algal blooms. Although mucilage is a harmless organic material structurally, studies have indicated that mucilage is home to various harmful microorganisms including pathogenic species (e.g. bacteria and viruses) (Del Negro et al. 2005; Precali et al. 2005; Danovaro et al. 2009).

The highly productive and shallow Adriatic Sea within the Mediterranean Sea is reported as the area most severely affected by massive marine mucilage (Danovaro et al. 2009). The frequency of the mucilage phenomenon is indicated to have increased significantly in recent decades. Mucilage adversely affects seawater and makes it unsuitable for bathing due to the adherence of this mucus-like product on bathers' skin. Marine mucilage may float on the sea surface and then in the water column for a long-life span of two to three months and once settled on the benthos in the form of large aggregates, it coats the sediment, causing hypoxic and/or anoxic conditions (Precali et al. 2005). Consequently, suffocation of benthic organisms causes serious economic damage to tourism and fisheries (Rinaldi et al. 1995).

As an example, the semi-enclosed Marmara Sea was severely threatened by a mucilage outbreak in May 2021. The Marmara Sea is a semi-enclosed water body connecting the Mediterranean and the Black Sea via the Çanakkale (Dardanelles) and Istanbul Strait (Bosphorus). This system is formed by a two-layer current driven by a salinity gradient between the more saline (38 psu) and dense waters of the Mediterranean, flowing towards the Black Sea in the lower layer, while the less saline (18 psu) waters of the Black Sea move in the opposite direction. The strong and permanent stratification because of salinity, density and temperature gradient exacerbate the risks of pollution of biological or anthropogenic origin. Sea surface was covered with thick layers of foam on beaches and harbours, threatening marine life, tourism, fisheries, maritime traffic, and the economy. Fishing activities were temporarily halted to prevent potential sea-borne diseases and due to consumer reluctance. Although mucilage events in the Marmara Sea are not new or region specific, this instance was the most severe on record. The phenomenon has drawn increasing attention as it severely impacts overall ecology, particularly benthic organisms (Savun-HekiMoğlu et al. 2021).

3.3 Impacts on the socio-economic system

Some regions of the world are expected to be affected by climate change, which will act in most cases as a catalyst for already deteriorating socioeconomic and environmental conditions including low average per capita income, fast demographic growth, and conflicts in many countries in the MENA region and Africa (Ali et al. 2022). This is expected to cause distressed movements as a coping strategy, either within the region or toward Europe. Anticipated trends suggest that the Mediterranean region will experience climate-induced migration due to extreme weather events in the affected nations since it is expected to confront the gradual and incremental impacts of climate change (Moatti and Thiébault 2016). Importantly, it is challenging to determine the precise number of individuals currently displaced by climate change effects within the region (Moatti and Thiébault 2016).

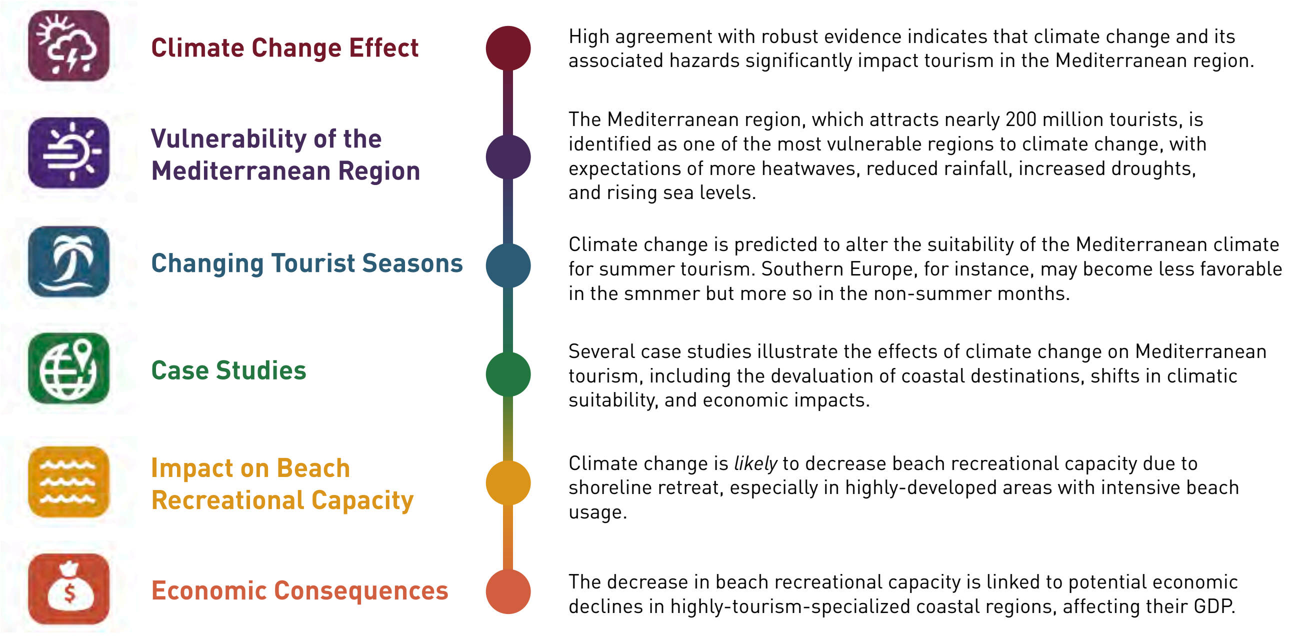
3.3.1 Impacts on tourism

The impact of climate change on the tourism industry in the Mediterranean, a region that draws nearly 200 million tourists annually, illustrates a critical challenge. Increasing heatwaves, reduced rainfall, and rising sea levels threaten its tourism-driven economy, necessitating urgent examination and adaptation strategies.

There is *high agreement* with *robust evidence* that climate change and its induced hazards impact tourism (Perch-Nielsen et al. 2010; Seetanah and Fauzel 2019; Arabadzhyan et al. 2021) *(high confidence).* The Mediterranean region, the destination for almost 200 million tourists, is known as one of the most vulnerable regions to climate change (Stratigea et al. 2017; Cannas 2018; Rick et al. 2020). The region is expected to face more intense and frequent heatwaves, a significant decrease in rainfall, an increase in periods of drought, and an increase in sea levels (Galeotti 2020), all of which will *likely* influence the tourism industry in the region (Perry 2000; World Tourism Organization 2008; Anfuso and Nachite 2011; Dogru et al. 2016; Rizzetto 2020). It has been predicted that the Mediterranean region will become excessively hot for tourists' comfort in the summer months (Amelung and Viner 2006; World Tourism Organization 2008; Rutty and Scott 2010; Arabadzhyan et al. 2021). For instance, the suitability of southern Europe to appeal to tourists will decrease during the summer holiday months but improve between October and April (Perch-Nielsen et al. 2010). Climate change *likely* changes the destinations and seasonal distribution of tourism (Ciscar et al. 2011; Amengual et al. 2014; Koutroulis et al. 2018), tourist activities (Caldeira and Kastenholz 2018), and alter tourism flows as well (World Tourism Organization 2008; Magnan et al. 2013).

Moreno (2010) found that while climate is a significant consideration for Mediterranean tourists, heat waves are considered the least consequential factor. However, projections by Amelung and Viner (2006) indicated spatial and temporal changes in climate attractiveness, which would affect the sustainability of tourism development, making spring and autumn more desirable *(high confidence).*

There are various case studies on the impacts of climate change on tourism in the Mediterranean region. El-Masry et al. (2022) argued that climate change will cause devaluation of coastal tourist destinations and thus a decline in revenues for the El Hammam–EL Alamein region in Egypt. They predict a downward shift in the region in terms of tourism climate suitability in the future. Abo El Nile (2017), through survey research for MENA countries, showed the impact of climate change on beach tourism in the region and discussed the need to anticipate changes and to adapt. Katircioglu, et. al. (2019) presented positive climate change influences on foreign tourist flows to Cyprus and Malta. Enríquez and Bujosa Bestard (2020) found the negative impact of climate-induced environmental change on tourist attractions by measuring economic impacts on the coast of Mallorca (Spain). Vrontisi et al. (2022) also found harmful impacts of climate change on the tourism sector in the southern European islands (Baleares, Crete, Cyprus, Malta, Sardinia, and Sicily). Hall and Ram (2018) analysed the negative influences of climate change on coastal tourism in Israel. In summary, there is *high confidence* that climate change influences tourism and consequently affects Mediterranean economies. While increasing temperatures might conceivably diminish the suitability of the Mediterranean climate for summer tourism, one could argue that there might be a rise in tourist visits during alternative seasons like winter, autumn, and spring. Therefore, the potential negative impact on Mediterranean economies is debatable, as it could result in an



Climate Change Effect

High agreement with robust evidence indicates that climate change and its associated hazards significantly impact tourism in the Mediterranean region.

Vulnerability of the Mediterranean Region

The Mediterranean region, which attracts nearly 200 million tourists, is identified as one of the most vulnerable regions to climate change, with expectations of more heatwaves, reduced rainfall, increased droughts, and rising sea levels.

Changing Tourist Seasons

Climate change is predicted to alter the suitability of the Mediterranean climate for summer tourism. Southern Europe, for instance, may become less favorable in the smnmer but more so in the non-summer months.

Case Studies

Several case studies illustrate the effects of climate change on Mediterranean tourism, including the devaluation of coastal destinations, shifts in climatic suitability, and economic impacts.

Impact on Beach Recreational Capacity

Climate change is *likely* to decrease beach recreational capacity due to shoreline retreat, especially in highly-developed areas with intensive beach usage.

Economic Consequences

The decrease in beach recreational capacity is linked to potential economic declines in highly-tourism-specialized coastal regions, affecting their GDP.

Figure 3.6 | Key points on climate change impact on Mediterranean tourism.

overall increase in tourism spread across seasons rather than being concentrated solely in the summer.

One of the most direct impacts of climate change on coastal tourism along the Mediterranean Basin is *likely* the decrease in the recreational beach carrying capacity (BCC) as a consequence of the projected increase in shoreline retreat (see *Chapter 3, Section 3.2.2*). This is due to the decrease of available beach surface for recreational purposes due to beach narrowing (in areas with a rigid landward boundary limiting the accommodation space as tourist beach areas used to be) with the corresponding increase in density of users during the first stages, which will be followed by the decrease in beach users as density exceeds beach saturation values (Valdemoro and Jiménez 2006; Rodella et al. 2017). This risk is *very likely* to occur in highly developed areas with beaches of intensive use such as the Spanish, Italian, French and Greek coasts. López-Doriga et al. (2019) therefore estimated that by 2050, without adaptation, the beaches along the Catalan coast (Spain, north-western Mediterranean) will potentially experience an overall 19% decrease in BCC under current conditions, increasing to 36% under RCP8.5. For coastal counties highly specialised in tourism, this represented a potential decline in their GDP of between 18% and 26% under RCP8.5 by the end of the century (Garola et al. 2022). *Figure 3.6* provides a concise summary of the impacts of climate change on Mediterranean tourism.

As a final conclusion, existing research reveals climate change's multifaceted effects on Mediterranean tourism, suggesting a shift towards alternative seasonal tourism as a potential mitigation strategy. Adaptive measures are essential to harnessing opportunities and mitigating economic impacts, ensuring the region's tourism sustainability in the face of climate change.

3.3.2 Impacts on food security and agriculture

Climate change is one of the critical environmental challenges for production systems in the Mediterranean area (Capone et al. 2020; Hossain et al. 2020) and is expected to threaten agriculture (Aguilera et al. 2020; Kavadia et al. 2020). It is expected to reduce food production in the region (Grasso and Feola 2012; Galeotti 2020) and negatively impact the biodiversity of agriculture (Palatnik and Lourenço Dias Nunes 2015; Galeotti 2020), fisheries and aquaculture (see *Section 3.3.3*). Crop yields for winter and spring are expected to decline because of climate change, especially in the southern Mediterranean (Galeotti, 2020). In addition, climate change will influence the growth cycles of crops and could

result in significant limitations in this regard (Funes et al. 2021). On a sub-regional scale, North African countries, due to their limited adaptive capacity, face higher vulnerability to climate change's impact on agriculture compared to northern Mediterranean countries (Atay 2015).

As introduced before, climate change is presently exerting adverse effects on regional water availability, and climate change is intensifying the ongoing trend of reduced water availability (see *Section 3.2.4*). Since agriculture is the leading water consumer in the Mediterranean region (Daccache et al. 2014; Pool et al. 2021), this expected decrease in water resources will affect agriculture (García-Garizábal et al. 2014; Papadopoulou et al. 2016), with significant detrimental ramifications on the productivity of crops, including orchards and vineyards (Del Pozo et al. 2019). Due to climate change, the Mediterranean area may need between 4 and 18% more water for irrigation (Fader et al. 2016; MedECC 2020b). Brouziyne et al. (2018) predicted a 26.4% decrease in Mediterranean water yield and a 44.7% decrease in crops produced by rainfall (winter wheat, and sunflower) by 2050. Decreased spring rainfall due to climate change would therefore result in a decrease of rain-fed crop production. In addition, climate change could harmfully impact intensive dairy farming in terms of milk production and quality, and cattle mortality (Dono et al. 2016).

Another impact of climate change on agriculture is soil degradation as climate change threatens the natural capital of soils (Ferreira et al. 2022). Kourgialas et al. (2016) predicted considerable soil erosion with a mean annual loss of 4.85 t ha^{-1} yr^{-1}. This study highlighted that soil loss would increase by 32.44% and 50.77% in 2030 and 2050, respectively, compared to current conditions (Kourgialas et al. 2016).

Various case studies focus on the impacts of climate change on agriculture and food production. In Egypt, according to projections by Fawaz and Soliman (2016), by 2030, the cultivated area is anticipated to decrease to approximately 0.949 million acres, and the crop area will decrease to about 1.406 million acres. These figures represent approximately 8.22% and 6.25% of the current area, respectively. Consequently, the value of Egyptian agriculture production would decrease by about 6.19 billion US dollars (Fawaz and Soliman 2016). Salinity in the soil in the Nile Delta coast would rapidly increase and organic matter content will decrease, especially during the summer season (El-Nahry and Doluschitz 2010). In Türkiye, the yield of crops would decrease at a growing rate due to climate change (Bozoglu et al. 2019). In Andalucia (southern Spain), climate change could cause a 95% reduction in sunflower crops by 2100 in addition to a decline in wheat production (Abd-Elmabod et al. 2020). Bosello et al. (2013) predicted an average production loss of 0.5% for the agricultural sector of southern and eastern Mediterranean countries.

In addition, there are studies focused on the detrimental impact of climate change on particular products in parts of the region, including orchards (Del Pozo et al. 2019), grapevines (Ferrise et al. 2016; Del Pozo et al. 2019), viticulture (Santillán et al. 2020), wheat (Ferrise et al. 2016; Dixit et al. 2018; Zampieri et al. 2020; Reyes et al. 2021), durum wheat (Ferrise et al. 2011), barley yield (Cammarano et al. 2019), olives (Ponti et al. 2014; Fraga et al. 2020a, 2020b; Rodrigo-Comino et al. 2021), and rice (Bregaglio et al. 2017) in the eastern Mediterranean and the Middle East (Constantinidou et al. 2016). For mushrooms, unlike the results for the other products, Karavani et al. (2018) predicted higher fungal productivity for 2016–2100 compared to current mushroom yields. Moreover, Atay (2015) anticipated a 1.1% rise in wheat yields, 0.36%, and 0.67% decline in maize yields, and 2.0% and 2.8% increase in potato yields due to a 1% increase in temperature in two groups of countries in the Mediterranean region.

Reduced crop yields, combined with population growth and urbanisation, increasing competition for water, and changing lifestyles, including diets, are also expected to impact food security in the Middle East and North Africa (MENA) region (Jobbins and Henley 2015). A typology of the impacts of coastal risks, mostly driven by climate change, on agriculture and food security can be proposed. First, the direct impact of coastal risks (from climate change) on agriculture: loss of agricultural productivity in coastal areas (but not necessarily due to the location of crops and livestock near coasts); loss of ecosystem services associated with food provision (Mehvar et al. 2018), depletion of natural resources, especially nutrients and water. The latter is due to salt intrusion linked to sea level rise and over-pumping from groundwater resources (Mastrocicco and Colombani 2021). For agroecosystems, salinisation of soils may cause changes to the distribution of plants and animals, while seawater intrusion is expected to cause additional risks in coastal aquifers, with severe impacts on agricultural productivity (Ali et al. 2022).

Secondly, a direct impact on total agricultural output is due to land loss because of coastal erosion, and loss of some farm infrastructure (access roads, agricultural buildings, irrigation networks, etc.). For example, farmland may be converted to tourism-related areas because of coastal erosion (Luisetti et al. 2008), while in some cases farmland is lost ('coastal squeeze') to wetlands that 'retreat' onto agricultural land that cannot no longer be cultivated because of submersion (Kuhfuss et al. 2016). Erosion and salinisation are already harming soil contents and production capacity in the Mediterranean region, with previously fertile soil prone to desertification, and these factors of reduced agricultural land are exacerbated by climate change (ARLEM 2021). As pointed out by FAO (2015), reduced livelihood options in coastal regions will force occupational changes and may increase social pressures, because livelihood diversification as a means of risk transfer will be reduced (e.g. between farming and fisheries).

Thirdly, indirect impacts due to land use change because global trends connected or not to climate change will also affect agricultural activities in coastal areas. Moreover, water availability and quality in coastal areas will probably diminish due to saltwater intrusion driven by enhanced extraction and SLR, also because of increased water pollution from urban sprawl, tourism development and population growth (Hinkel et al. 2014). Population growth in coastal areas will mechanically increase demand for local food, with increased demand for irrigation water as a corollary, particularly in the coastal areas of eastern and southern Mediterranean countries (Cramer et al. 2018).

Local ecosystem-based and nature-based solutions (e.g. conservation and revegetation projects, Integrated Coastal Area and River Basin Management) that may reduce the impacts of coastal risks on agriculture in the Mediterranean have been proposed in UNEP/MAP and Plan Bleu (2020). Joshi et al. (2016) estimate the economic impacts of SLR on regions including Africa and the Middle East, to conclude that economic impacts due to loss in cropland without protection are low (compared with loss of capital, change in labour supply and government

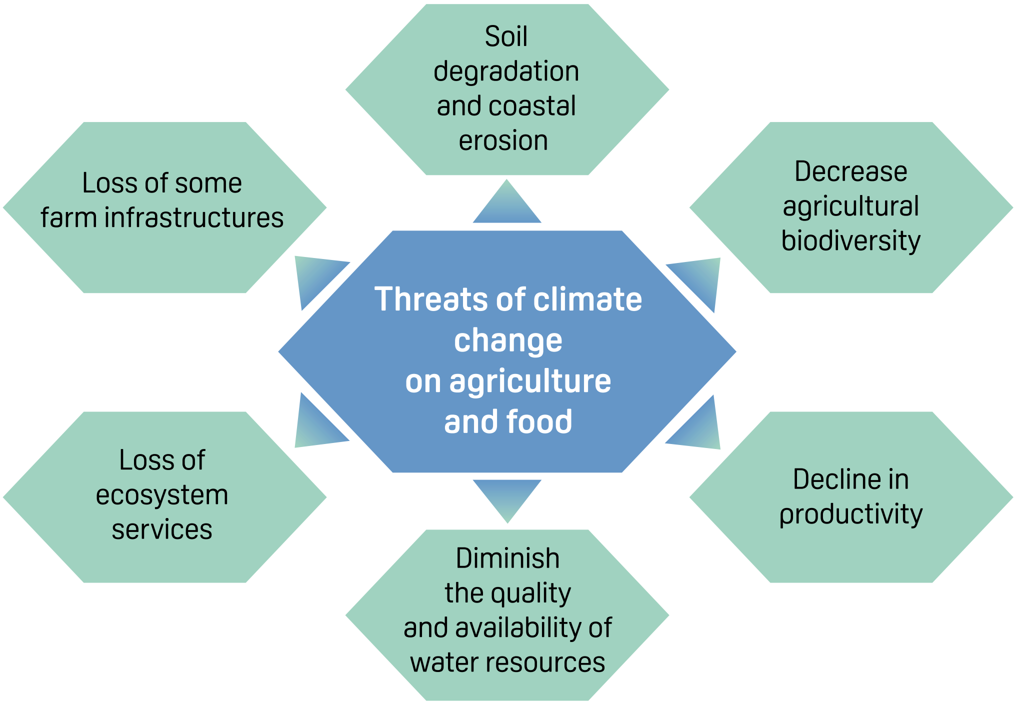


Figure 3.7 | **Key climate change threats to agriculture and food security at a glance.**

expenditure on migration), and that the economic impact of SLR is affecting South-East Asia, Australia and New Zealand potentially the most. Note also that, given the limited share of total agricultural output of MENA countries (except for Türkiye), coastal risks due to climate change in the MENA region are not *likely* to have a strong impact on global markets for agricultural commodities (C.-C. Chen et al. 2012). *Figure 3.7* shows an overview of the pivotal climate change threats to agriculture and food security.

As a final conclusion, the diverse studies on climate change's impact on Mediterranean agriculture reveal a sad picture: declining crop yields, exacerbated soil degradation, and increased water demands for irrigation. This situation underscores a move toward more adaptive measures and enhanced research focusing on underrepresented crops and the indirect effects of land use change. Dealing with these challenges through comprehensive policy design and informed decision-making is essential for securing the region's food security in the face of climate change.

Confidence level and knowledge gaps

There is a particular need for research into various aspects of climate change in relation to agriculture and food security. First, more research is necessary on the impact of climate change for crops and products less present in the agricultural literature than orchards, grapevines, viticulture, wheat, barley, olives, and rice in particular. Secondly, several issues could not be addressed due to a lack of data, in particular the expected decrease in local water resources that will affect agriculture at the landscape (or small river basin) level. Uncertainty about the extent to which the Mediterranean area may need more water for irrigation may be reduced by collecting more comprehensive data on the extent of soil degradation (as climate change threatens the natural capital of soils). Moreover, uncertainty remains on the indirect impacts on coastal areas due to land use change, because changes at the global level (associated or not with climate change), will impact agriculture in these areas. Water availability, and water quality, will probably be reduced because of saltwater intrusion due to excess resource extraction and SLR, but also because of increased water pollution from urban expansion and population growth. However, more case studies on a larger set of contrasted settings in the Mediterranean region are necessary to obtain a more representative vision, which could provide guidance for policymaking and decision makers.

Finally, better knowledge of local expected impacts and data collection efforts, especially in the southern and eastern Mediterranean, are needed to provide a more effective plan for action, as the majority of scientific literature addresses coastal risks and agriculture in South Asian countries, the United States and Pacific Islands (Kumar et al. 2022) or for large world regions excluding the MENA region (Bosello et al. 2007).

3.3.3 Impacts on fisheries and aquaculture

When considering Mediterranean fisheries and aquaculture, climate change significantly affects species diversity, distribution, and productivity. The region's fisheries, renowned for their rich biodiversity and intricate socio-economic dynamics, face increasing pressure from overexploitation and environmental shifts. These challenges intensify the vulnerability of marine ecosystems and the communities reliant upon them.

Mediterranean fisheries are extremely diverse because of the heterogeneity of the sea with respect to the number of species harvested, variety of fleets, hydrography, bathymetry, and productivity (Barange et al. 2018), but also to the varying cultural, social and economic conditions across the Mediterranean coastline (Stergiou et al. 2016). Nearly 400 species of fish, crustacean, and molluscs are being fished by numerous types of fishing gear and methods in the Mediterranean Sea, yielding over one million tonnes of catches per year according to official statistics. (FAO 2022) Recent studies based on scientific surveys, stock assessments and catch data, generally agree that the Mediterranean fisheries are overexploited, with the majority of fish stocks experiencing a decline in biomass (Cardinale and Scarcella 2017; Colloca et al. 2017). The cumulative percentage of collapsed and overexploited stocks was reported to exceed 60% (Tsikliras et al. 2013) with the exploitation pattern differing among the Mediterranean subareas (Tsikliras et al. 2015). Local reports also confirm the overexploitation of Mediterranean fisheries (e.g. Greek seas: Tsikliras et al. 2013; Ligurian Sea: Abella et al. 2010; Turkish seas: N. Demirel et al. 2020), which is often attributed to poor or inadequate management practices (Tsikliras and Stergiou 2014; Cardinale and Scarcella 2017). Finally, there is *high confidence* that the exploitation rate in the Mediterranean is steadily increasing and gear selectivity deteriorating; both conditions are *likely* leading to shrinking fish stocks (Vasilakopoulos et al. 2014).

Climate change is adversely affecting the range and quantity of species available (*high confidence*; Costello et al. 2022) and is leading to changes in fisheries (Brander 2007) and the emergence of non-indigenous species (*high confidence*; Costello et al. 2022). The progressive occurrence and establishment of warm-water species (Lloret et al. 2015) *likely* generates both positive and negative effects on fisheries (Hidalgo et al. 2018), especially on small-scale fisheries because of their socio-economic and ecological sensitivity. These generalised effects can be listed as (1) increase of warm water species such as bluefish *(Pomatomus saltatrix)* and barracuda (*Sphyraena viridensis*) as examples of 'Meridionalisation' in northern Mediterranean areas *(medium confidence)*; (2) presence of Indo-Pacific species (Lessepsian migrants) in the eastern Mediterranean (Boero et al. 2008) as evidence of 'Tropicalisation' *(high confidence)*, and (3) extension of the distribution ranges of Mediterranean species and detection of non-indigenous species in the Black Sea, called as 'Mediterranisation' *(low confidence).* There is *high confidence* that non-indigenous species compete with native species (e.g. rapa whelk – *Rapana venosa*; N. Demirel et al. 2021) or include highly damaging toxic species such as pufferfish (e.g. silvercheeked toadfish – *Lagocephalus sceleratus*; (Ünal and Göncüoğlu Bodur 2017). Some studies have considered the impacts of climate change on species and stocks, including trout (climate change influences the largest, oldest trout through increased metabolic costs) (Ayllón et al. 2019); finfish aquaculture in Greece (Stavrakidis-Zachou et al. 2021; Aragão et al. 2022); demersal fisheries (Aragão et al. 2022); shellfish (Martinez et al. 2018; Carosi et al. 2019); endemic freshwater fishes (*Padogobius nigricans, Squalius lucumonis* and *Telestes muticellus*) in the Tiber River basin (Italy) (Carosi et al. 2019).

Future projections show that regional changes in fish abundance and their distribution will *likely* alter species diversity, with an expected increase in overall diversity by the mid-21st century in the eastern Mediterranean, and a decrease in the western region (Sinclair and Valdimarsson 2001; Albouy et al. 2013). A *likely* decrease in connectivity between neighbouring ecosystems within the Mediterranean is expected due to a decrease in the size of the spawning areas and an increase in larval retention on smaller areas of the continental shelf. Fish often move between marine ecosystems, making them difficult to track, count and assess (Sinclair and Valdimarsson 2001). Each species has a unique reproductive strategy and behavioural, physiological, and energetic adaptations, which comprise their ecological niche. Healthy fish populations therefore ultimately depend on the collaborative success of their spawning *(very likely)* and reproductive seasons, as well as prey availability *(very likely)*, especially in changing environments under climate change.

Aquaculture plays an important role in the Mediterranean economy (Cubillo et al. 2021). The average per capita consumption of seafood in the Mediterranean region is 16.5 kg per year, and aquaculture activities provide almost 25% of it (Rosa et al. 2012, 2014). Climate change is *likely* expected to have direct and indirect effects on the aquaculture sector (FAO 2020). There is a virtually certain connection between the temperature preferences of aquatic species, and their oxygen demands (Barange et al. 2018; Pauly 2019). Specifically, the oxygen concentrations required to meet the maximum oxygen demand for organisms determines their temperature preference. Exposure of fish to temperatures beyond their adaptive range to leads to changes in their physiological responses and increases in stress levels (Bell et al. 2018). In the short term, although rising water temperatures *likely* increase the forage availability and growth rates of organisms, these rates will decrease as temperatures continue to rise, as cultivated species have limited space to move (Crozier et al. 2008). Optimal areas for aquaculture are therefore expected to shift towards the poles. As a result of climate change, extreme weather events such as strong winds and waves will *likely* damage facilities such as cages and platforms used in shell and fin aquaculture and cause negative consequences such as losses of brood stocks and significant damage to facilities. Possible flooding in flat coastal areas at sea level suitable for breeding brackish water species is also predicted (FAO 2020).

Final remarks

The socio-economic importance of fisheries and aquaculture in food security and economic development, as well as in generating employment and income, requires a proactive approach in the development of adaptation and mitigation policies regarding climate change and aquaculture interactions. Raising awareness and understanding the perceptions of stakeholders about the impact of climate change on fisheries is an important pillar of the adaptation and/or mitigation policy development process.

Sustainable fishery management is needed to ensure long-term optimal resource use. To effectively manage fish stocks, various control measures exist that directly or indirectly limit catches. However, the diversity of multiple types of fishing gear and target species makes fisheries management applications even more complex. In the Mediterranean Basin, which is more heavily affected by climate change and human-induced pressures than the global seas, intensive efforts are necessary to develop responsive fisheries management. This, for example, includes timely restriction on fishing and protection of spawning stocks by way of fishery closure to minimise the amplified impacts of excessive fishing and environmental change. Continued expansion of the fishing capacity in the absence of effective and restrictive management actions may exacerbate the risk of overexploitation. While considering the social, legal, and economic drivers fostering fleet growth, a bottom-up governance approach for the well-being of small-scale fishers is greatly needed.

As a final remark, addressing climate-induced impacts on the fishing and aquaculture sectors, while safeguarding their sustainability and contributions to regional food security and economic stability, can be advanced through stakeholder collaboration, research-driven insights and ecosystem-based approaches.

3.3.4 Impacts on water and energy security

As the impacts of climate change intensify, the Mediterranean region is facing growing threats to its water and energy supplies. Decreased rainfall and more frequent heatwaves are already straining the region's natural resources, underscoring the pressing need for strategic planning to address these vulnerabilities.

Climate change affects water security adversely (Al-Jawaldeh et al. 2022; Daoudy et al. 2022; Marangoz and Daloglu 2022). It can substantially

decrease water yield, surface runoff, groundwater recharge, and baseflow in the Mediterranean region (Pulighe et al. 2021). Some studies have emphasised this effect for Mediterranean countries such as Algeria (Bouregaa 2022), Cyprus (Gökçekuş et al. 2021), Egypt (Alkhawaga et al. 2022), Morocco (Hadri et al. 2022), Palestine (Sarsour and Nagabhatla 2022) and Türkiye (Gümrükçüoğlu Yiğit 2022). In addition, Iglesias et al. (2011) highlighted challenges to water resources in Mediterranean countries and outlined the risks and opportunities for water under climate change. Chenoweth et al. (2011) predicted that precipitation would decline by 10% in the region by both the middle and the end of the century. It will not significantly change per capita water resources in the North, while it will significantly reduce per capita water resources in the eastern Mediterranean.

Likewise, it is expected that climate change will exacerbate challenges related to energy security in the Mediterranean region (M. A. Lange 2019; Drobinski et al. 2020). In urban areas, there is an expected increase in heat waves and droughts due to the major climate impacts such as rising temperatures and reduced precipitation, resulting in shortages of both water and energy (M. A. Lange 2019, 2022). To tackle climate change and its effects on energy security, Mediterranean economies need mitigation and adaptation strategies including enhanced efficiency of resource use, integrated technology assessments regarding electricity generation, and a stronger reliance on renewable/ solar technologies (M. A. Lange 2019). They are required in order to adopt accelerated energy transition policy and diversify the energy mix (Drobinski et al. 2020). It should be mentioned that climate change affects the pace of the energy transition (Flouros 2022). Baglivo et al. (2022) suggested zero-energy buildings for energy security and to combat climate change.

To cope with energy and water scarcities, Drobinski (2020) proposed integration of a regional energy market and cooperation as a mitigating strategy. Furthermore, M. A. Lange (2019) recommended an integrated water–energy nexus concept. Some studies have also focused on the Water–Energy–Food (WEF) nexus to address water, energy, and food security under climate change, including Riccaboni et al. (2022), Zebakh et al. (2022), and Bazzana et al. (2023).

3.3.5 Impacts on coastal infrastructure

Mediterranean coastal infrastructure faces escalating threats from climate change. Ports, airports, and transport networks are increasingly vulnerable to SLR, coastal flooding, and erosion. With approximately 150 million people residing in at-risk areas, the urgent need to strengthen these structures against forthcoming climatic shifts has never been more critical.

Coastal infrastructure in general, and ports in particular, are affected by different risks which can be increased by climate change in terms of stability and, fundamentally, in terms of functionality, mostly associated with increased coastal flooding and overtopping due to SLR (e.g. Sánchez-Arcilla et al. 2016; Arns et al. 2017; Izaguirre et al. 2021).

Around 150 million people live in coastal areas and port cities in the Mediterranean (Galeotti 2020). It is expected that by 2050, for the lower sea-level rise scenarios and current adaptation measures, 10 of the 20 global cities with the highest increase in average annual damage are in the Mediterranean, located in Algeria, Egypt, Libya, Morocco, Palestine, and Syria (Galeotti 2020). Erosion and flooding are two major threats to Mediterranean coasts and will cause damage to human settlements (Rizzetto 2020).

Furthermore, potential consequences of climate change may impact Mediterranean airports, putting them at risk (De Vivo et al. 2022). Therefore, airports located in coastal areas could be at risk of coastal flooding, which could be increased under SLR. Yesudian and Dwason (2021) conducted a global analysis of SLR risk for airports located in the Low Elevation Coastal Zone (LECZ) in terms of expected annual route disruption. In the Mediterranean, three airports were ranked in the top 20 at risk by 2100 which are Venice and Pisa in Italy, and Ioannis Kapodistrias Intl in Greece.

In coastal areas, SLR is the most important and *likely* climate change-driver to affect infrastructure in general (de Almeida and Mostafavi 2016), and transport networks in particular (H. Demirel et al. 2015). This is especially evident when coastal plains supporting such infrastructure are flooded episodically or permanently (e.g. Armaroli et al. 2019; Antonioli et al. 2020). In some cases, SLR will increase the number of disruptions currently taking place under the impact of storms in transport networks close to the shoreline, such as the coastal railway along Catalonia (Jiménez et al. 2018). The location of such infrastructure very close to the shoreline significantly increases the risk due to high exposure that usually forces them to implement specific protection measures (e.g. see Pranzini (2018) for protection works in Italian coastal railways). In any case, it should be kept in mind that this infrastructure will be subject to greater risks of disruption not only due to increased overtopping under SLR, but also due to a future scenario of narrowing protective beaches in front of them due to SLR-induced erosion.

For the Thessaloniki area in Greece, Papagiannakis et al. (2021) estimated that under a SLR of 0.5 m and 1 m, about 1.87% and 3.07% respectively of the total length of the coastal road network will be covered by the sea by 2100, and the access road to the airport might be interrupted. For Türkiye, Karaca and Nicholls (2008) found that capital loss from the impacts of a 1 m rise in sea level could be significant (about 6% of current GNP). For Malta, Attard (2015) highlighted that environmental change could heavily damage the island's infrastructure and disrupt the transport systems.

Izaguirre et al (2021) estimated an increase in risk for Mediterranean ports by 2100 under the RCP8.5 scenario, which changes from medium or low risk to very high or high future risk, respectively due to increased overtopping and coastal flooding risk. The western African

Mediterranean ports were identified as subject to very high risks. Furthermore, it is essential to take into account indirect impacts, as highlighted by Christodoulou et al. (2019), who estimated that disruptions in northern European ports due to SLR could significantly affect the operations of Mediterranean ports.

At regional scale, Sierra et al. (2016) assessed the impact of SLR on the operability of harbours along the Catalan coast in the western Mediterranean due to increasing overtopping during storms. They found a significant increasing risk in nearly all harbours under a high-end scenario of SLR of about 1.8 m, although results obtained for the median RCP8.5 scenario presented significantly less risk.

In Egypt, the Nile Delta's four principal fishing harbours are at high risk (Abutaleb et al. 2018). Port Said in the Nile Delta would be the most affected in the MENA region (Dasgupta et al. 2009), and the economic damage due to the 0.5 m and 1.25 m SLR scenario is estimated to be more than US$2.0 billion and US$4.4 billion, respectively (El-Raey et al. 1999). For Rosetta, this number is expected to be US$2.9 billion (El-Raey 2010). Refaat and Eldeberky (2016) estimated that almost 7% of the Nile Delta area would be at risk of inundation due to future sea-level rise. In addition, El-Masry et al. (2022) predicted that climate change might damage the coastal infrastructure in El Hammam-EL Alamein, and 34 to 36 (about 46.5% to 49.3%) of the existing coastal resorts could be inundated. For Morocco, Kasmi et al. (2020) highlighted the risk of erosion and soil loss in response to SLR (the loss of more than 50% of width with a 2m SRL scenario on many beaches). In the Tangier Bay, Morocco, Snoussi et al. (2009) noted that coastal defences and the port, tourist coastal infrastructure, the railway, and the industrial area are expected to be at risk due to climate change and estimated that erosion of the shoreline would affect nearly 20% of the total beach areas by 2050 and 45% by 2100. Snoussi et al. (2010) calculated climate change impacts on the various Moroccan coasts, finding that 70% of most of the urbanised sections of the Tetouan coast would suffer from erosion,

In Israel, Zviely et al (2015) found that SLR is expected to cause extensive damage to port infrastructure, including seaports, power plants, marinas, desalination plants, sea walls, detached breakwaters, and bathing beach infrastructure, and to the vessels moored inside, as well. For 0.5 m and 1 m SLR, respectively, at a cost of approximately US$200 million and US$500 million (0.07% and 0.17% of Israel's GDP for 2012), the current level of operation of this infrastructure can be maintained (Zviely et al. 2015).

Finally, in terms of existing coastal protection measures, one of the most sensitive structures to SLR are parallel breakwaters since their protection capacity depends on the relative height with respect to mean water level which controls wave energy transmission. Consequently, sea-level driven changes in wave characteristics and the structure relative height may significantly change their design conditions and increase the exposure of the protected area (Arns et al. 2017). In simple terms, the (economic) impact will be associated with the need to increase the height of the structure to maintain its design conditions. As an example, Vousdoukas et al. (2018) estimate that upgrading existing coastal protection would imply increasing elevations by an average of at least 25 cm by 2050 and by more than 50 cm by 2100, although local required increments can be significantly higher. The importance and relevance of this impact along the Mediterranean will be determined by the local conditions of the existing structures, although due to the extensive and intensive use of parallel coastal breakwaters as a protection measure, it is expected that one of the areas with the greatest impact will be the Italian coast.

In conclusion, the coastal infrastructure of the Mediterranean region faces imminent threats from the challenges posed by climate change. Failure to act could result in significant disruptions to the region's economic prosperity and environmental health. To mitigate these risks, a proactive stance is essential in both designing and managing infrastructure capable of withstanding the increasing hazards associated with climate change.

3.4 Impacts on human systems

3.4.1 Impacts on cultural heritage (natural and built)

The cultural and natural heritage of the Mediterranean, encompassing ancient ruins and stunning landscapes, faces threats from sea level rise and increasingly harsh climates. The potential impact on natural and built heritage in coastal regions is caused both by on-going variations of climate and environmental parameters responsible for slow cumulative damage processes and by hydrometeorological extreme events. Natural landscapes, archaeological sites and monuments are exposed to an aggressive and worsening environment, characterised by local land subsidence, coastal flooding, and erosion (see *Chapter 2*). Sea level rise risks submerging natural landscapes and built heritage. The Mediterranean coast includes several natural landscapes with their wildlife, such as the biodiverse wetlands of Camargue on the delta of the Rhône River, France (Fraixedas et al. 2019) and Doñana National Park, Spain (Camacho et al. 2022). Detailed maps of the UNESCO cultural World Heritage Sites (WHS) located in the coastal zone at risk, and their projections to 2100 have been reported by Reimann et al. (2018b), who, based on the analysis of spatially explicit WHS data and the development of an index-based approach, show that of 49 cultural WHS located in low-lying coastal areas of the Mediterranean, 37 are at risk of flooding for a 100-year return period and 42 from coastal erosion, already today. Until 2100, flood risk may increase by 50% and erosion risk by 13% across the region. Projections are provided under RCP2.6, RCP4.5 and RCP8.5. Analysis done by Kapsomenakis et al. (2023) shows evidence that coastal UNESCO heritage sites in the Aegean Sea, the Adriatic coastline and the Gulfs of Genoa and Venice could be significantly at risk in the future period 2071-2100 under the RCP8.5 scenario due to sea level rise. The most famous city at risk is Venice, sinking under the combined action of sea level rise and local land subsidence (Lionello et al. 2021; Camuffo 2022). In the long run, currently still subaerial archaeological sites risk being completely submerged as has been the case for Capo Rizzuto (southern Italy), Alexandria (Egypt), Pavlopetri and Peristera (Greece), Caesarea Maritime (Israel), Kizlan (Türkiye), and several other Mediterranean harbours (Marriner et al. 2017). At present, storm surges are affecting buildings and archaeological sites. In the future, this challenge will continue with increasing frequency and flooding depth.

The available projections of the impact that climate change will have on built heritage in terms of slow cumulative deterioration processes developed in the framework of the two EU funded programmes, Noah's Ark (Bonazza et al. 2009a,b; EC et al. 2010) and Climate for Culture (Leissner et al. 2015), highlight that the Mediterranean coastal heritage sites are *likely* expected in the far future (2071–2100):

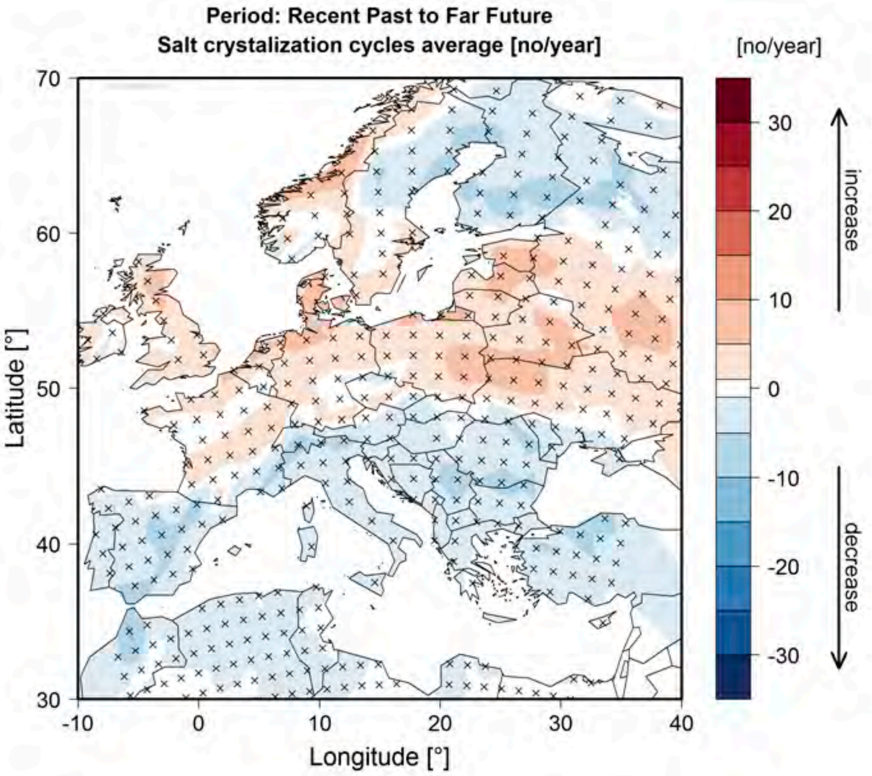


Figure 3.8 | Projected change in the yearly frequency of NaCl crystallisation indoors. The data are calculated as a difference between the far future the far future (2071–2100) and the 1961–1990 reference period. Project Climate for Culture, simulation for an unconditioned building type 02 (average brick structure), under the RCP4.5 emission scenario (Camuffo et al. 2015; Leissner et al. 2015).

- to undergo more than 30 events per year of relative humidity cycles crossing 75.5%, implying a potential risk of decohesion and fracturing of porous building materials, such as sandstones, mortars and brick, caused by crystallisation pressure of soluble salts (Camuffo 2019). Salt weathering is mainly driven by a phase change. The damage arises during the crystallisation-dissolution cycles, which occur under precise temperature and humidity conditions. Non-hydrated salts, such as sodium chloride (NaCl), crystallise at a fixed relative humidity (RH) virtually independent of temperature (RH threshold = 75.5%), whereas phase transitions in hydrated salts, such as sodium sulphate, are sensitive to both relative humidity and temperature (Bonazza 2022);

- to presumably experience higher levels of biodeterioration, with a value of total biomass accumulation from 5 to 15 mg cm^{-2} (EC et al. 2010);

- to undergo surface recession linked to chemical dissolution of 5–35 μm yr^{-1}, particularly monuments in marble and compact limestone located in highly polluted coastal areas (Bonazza et al. 2009a);

- to increasingly suffer from thermal stress caused by solar radiation with more than 150 events per year of internal tension >20 MPa. This threshold of internal tension is considered particularly dangerous for marbles and can cause decohesion and powdering (Bonazza et al. 2009b).

Examples of the projected change in the yearly frequency of the NaCl crystallisation cycles calculated for building materials exposed to indoor climate variations are shown in *Figure 3.8.* This map has been expressed in terms of change as a difference between the far future (2071–2100) and the recent past reference period (1961–1990). The projection shows a slight decrease of the structural risk for the built heritage across the whole Mediterranean coastal area.

Research has only recently started to focus on the development of projections of extreme events (i.e.

heavy rain, flash floods, drought) linked to climate change to assess the risk consequently imposed on natural and cultural heritage. This has been specifically addressed in the framework of two EU funded Projects ProteCHt2save[42] and STRENCH[43]. The analysis demonstrated that the impact linked to extreme variations of precipitation and temperature on monuments and archaeological sites in the Mediterranean regions is *likely* to increase in the near and far future (Bonazza et al. 2021).

3.4.2 Impacts on human health

3.4.2.1 Impacts of climate and geological hazards on human health

Climate and geological shifts in the Mediterranean Basin pose increasing risks to human health, with longer, hotter summers and severe weather events such as floods and fires. These environmental changes threaten the physical and mental well-being of coastal populations.

The Mediterranean Basin is one of the world regions most profoundly influenced by changes in climate and geological factors (Giorgi 2006; MedECC 2020b; Tuel and Eltahir 2020). Serious health issues can emerge from longer and warmer summers, more sever heatwaves (or extreme events such as floods and fires in coastal areas (Habib et al. 2010; Linares et al. 2020a; Neira et al. 2023). In addition, coastal populations are the most vulnerable to sea level rise.

The increase in storm-induced floods and gradual inundation will be accentuated in the future through climate change and this can lead to water-borne and respiratory diseases. The increased atmospheric pressure during thunderstorms can lead to the occurrence of severe asthma epidemics and initiate Idiopathic Spontaneous Pneumothorax (ISP). Increased humidity can also lead to mould allergies and the development of asthma in susceptible individuals (Habib et al. 2010). Extreme events, such as floods, often also disrupt medical care, with a particular impact on vulnerable populations such as those with chronic illnesses. Hospitals may be evacuated, transport of medication is more challenging, etc. In addition, electrical failures impact critical infrastructure (power, water, sanitation and sewer), with potential associated infectious diseases (waterborne pathogens). The impact on mental health is also to be considered, with potential post-traumatic disorder and depression.

Rising temperatures causing droughts, fires and heat waves (Wedler et al. 2023) are a serious threat to health in Mediterranean populations. Extreme droughts, which impact freshwater resources, can cause public health problems, including drinking water shortages and poor-quality drinking water. Reduced river flow can increase the concentration of pollutants in water and cause stagnation. Having water available for drinking, cleaning, sanitation, and hygiene is crucial for reducing many diseases. In the Mediterranean:

- 30% of the population lives in water-scarce countries;
- 220 million people suffer from water scarcity;
- 26 million do not have access to safely managed drinking water services;
- 160 million do not have access to safe sanitation (UNEP/MAP and Plan Bleu 2020).

Extreme heat leads to a significant increase in mortality and illness, including heat stroke and heat exhaustion (Lubczyńska et al. 2015; Gauer and Meyers 2019). As example, it is projected that in Israel, there will be approximately 330 additional deaths each summer under the RCP8.5 scenario in the late 21st century, especially among individuals aged 65 and above (Wedler et al. 2023), and other susceptible populations, including people with chronic health problems, outdoor labourers and military personnel were identified as individuals at greatest risk (Gauer and Meyers 2019; Watts et al. 2019). In Cyprus, Heaviside et al. (2016) anticipated that a 1°C temperature increase would lead to a doubling of heat-related mortality and a 5°C increase would result in a rate eight times

---

[42] https://programme2014-20.interreg-central.eu/Content.Node/ProteCHt2save.html

[43] https://programme2014-20.interreg-central.eu/Content.Node/STRENCH.html

higher than the baseline. In addition, heat exposure triggers multiple physiological mechanisms that cause damage to the brain, heart, intestines, kidneys, liver, lungs, and pancreas. The increased risk of heat-related mortality is particularly prominent in densely urbanised regions bordering the Mediterranean Sea, primarily attributed to the widely recognised phenomenon known as the Urban Heat Island (UHI) effect (Pyrgou and Santamouris 2018; Martinelli et al. 2020).

Lastly, more frequent wildfires (naturally or human induced) will impact air quality, particularly, affecting people with asthma, Chronic Obstructive Pulmonary Disease (COPD), or heart disease, and children, pregnant women, and firefighters.

Sea level rise is also associated with a greater risk of exposure to mould from increased humidity, which is responsible for respiratory diseases. Saltwater migrating upstream in freshwater systems increases salinity in rivers but also in groundwater basins, thereby directly or indirectly affecting human coastal population nutrition, through lower crop production or reduced availability of safe drinking water. Associated health impacts include higher risk of hypertension and diarrheal disease.

Furthermore, SLR-induced impacts are expected to lead to population displacement as livelihoods in coastal regions become increasingly threatened (Hauer et al. 2020). Reimann et al (2023) estimated that up to 20 million people could face permanent displacement within the Mediterranean region (within the same country) by 2100 in the absence of adaptation policies *(low confidence)*. This projection considered various combinations of SLR scenarios and Shared Socioeconomic Pathways (SSP), with the primary determinant being the population exposed in the Low Elevation Coastal Zone (LECZ). Consequently, it is more *likely* that the impact of population displacement will be significantly higher in the southern and eastern Mediterranean countries, as the exposure in these regions is approximately three times greater than that in the northern countries *(medium confidence)*.

3.4.2.2 Impacts of biological hazards on human health

Variable weather conditions (mainly temperature, rainfall and humidity) strongly influence the emergence of vector-borne diseases (diseases transmitted through insects) and water-borne diseases. Recently, several outbreaks have been observed and associated with local climate changes in the Mediterranean Basin region (Paz and Albersheim 2008; Paz et al. 2013). Currently, the main vector-borne diseases transmitted by mosquitoes and potentially exacerbated by the changing climate in the Mediterranean Basin, are West Nile Fever, Dengue, Chikungunya, Malaria, and Leishmaniasis (Paz et al. 2008; Colón-González et al. 2021). In addition, higher sea surface temperatures and heavy rainfall leading to an abrupt decrease in salinity can have a major effect on the abundance of pathogenic bacteria (Vibrio species) found in Mediterranean marine, lagoon and estuarine environments. These bacteria are recognised throughout the world as agents of gastroenteritis in humans resulting from the consumption of raw or undercooked seafood and serious infections caused by exposure of skin wounds to seawater (Guégan et al. 2018). In addition, when sewers carrying urban and industrial wastewater are overloaded, untreated sewage can flow into rivers, lakes, and coastal areas. This can lead to greater exposure of populations to contaminants, inadequate sanitation and unsafe drinking water (UNEP/MAP and Plan Bleu 2020).

3.4.2.3 Impacts of chemical hazards on human health

Coastal populations suffer from the cumulative burden of environmental pollution resulting from intense local activities and from upstream and inland development. When concentrated in small, confined, and overcrowded areas such as Mediterranean coastal zones, air and water pollution poses great threats to human health.

Two-thirds of the Mediterranean countries exceed the global WHO recommended threshold for air pollution from particulate matter and ozone even though air pollution has been linked to a broad spectrum of non-communicable diseases (diabetes, cardiopulmonary diseases, neurodegenerative diseases, etc.). In addition, high levels of noise caused by traffic can cause heart conditions and reduce cognitive functions in children.

Some areas around the Mediterranean Basin have concentrations of fine particulate matter ($PM_{2.5}$)

up to 100 $\mu g\ m^{-3}$ (world average: 39.6 $\mu g\ m^{-3}$, EU average: 14.2 $\mu g\ m^{-3}$) (UNEP/MAP and Plan Bleu 2020). In the Mediterranean, air pollution is the main environmental burden with 228,000 deaths per year (UNEP/MAP and Plan Bleu 2020). The impact of air pollution on health is generally much higher in SEMCs (southern and eastern Mediterranean Countries) than in NMCs (Northern Mediterranean Countries). Egypt is the country in the world with the highest death rate attributed to ambient air pollution (UNEP/MAP and Plan Bleu 2020).

Agriculture, coastal tourism and recreation, transport, port and harbour activities, urban and industrial development, mining, fisheries, and aquaculture are all sources of marine pollution. Marine pollution refers to thousands of physical, chemical, and biological entities such as toxic metals, petroleum, plastics, manufactured chemicals such as pharmaceuticals or pesticides, excessive nutrient load from agricultural runoff or sewage, Harmful Algal Blooms (HABs), etc. The Mediterranean is one of the regions of the world most affected by pollution with half of its coastal waters failing to achieve good environmental status (UNEP/MAP and Plan Bleu 2020). Above a certain level, these agents threaten the health of living beings. Coastal populations are particularly exposed to sea pollution (especially populations from low and middle-income countries) (Landrigan et al. 2020). In the Mediterranean, more than 500,000 deaths occur each year as a result of unhealthy environments. The rate of these premature deaths is two to three times higher in the southern and eastern Mediterranean countries and the Balkans than in EU countries (UNEP/MAP and Plan Bleu 2020). People can be exposed to chemicals through dermal contact, ingestion, inhalation or during development. Methylmercury and PCBs are ocean pollutants whose human health effects are best understood. Exposure of infants in utero to these pollutants through maternal consumption of contaminated seafood can damage developing brains, reduce intelligence quotient (IQ) and increase children's risks for autism, attention deficit hyperactivity disorder (ADHD) and learning disorders. Adult exposure to methylmercury increases the risks of cardiovascular disease and dementia. Because of their small size, microplastics are easily absorbed by organisms. Recently, studies have shown that microplastics are present in the human bloodstream and that microplastics cause damage to human cells at the levels known to be eaten by people via their food (Danopoulos et al. 2022; Leslie et al. 2022). In addition, plastics can provide transport and shelter to hazardous microorganisms, including vectors for human disease. Toxic chemical pollutants in the sea have been shown to be capable of causing a wide range of diseases in humans. Manufactured chemicals such as phthalates, bisphenol A, flame retardants and perfluorinated chemicals can disrupt endocrine signalling, reduce male fertility, damage the nervous system, increase the risk of cancer and cause cardiovascular and metabolic diseases. Harmful algal blooms (HAB) produce potent toxins that accumulate in fish and shellfish. When ingested, these toxins can cause severe neurological impairment and rapid death. HAB toxins can also become airborne and cause respiratory disease. Pathogenic marine bacteria cause gastrointestinal diseases and deep wound infections (Landrigan et al. 2020).

There are many thousands of types of man-made marine pollution for most of which available knowledge is very scarce, especially on the levels of exposure and magnitude of human health impacts. The majority of manufactured chemicals have never been tested for safety or toxicity: only about 700 out of 70,000 chemical substances on the market have been studied for their risk impacts (UNEP/MAP and Plan Bleu 2020). In addition, pollutants are rarely present in the environment in isolation but instead are found in complex mixtures. This creates even more uncertainties about the possible combined effects of exposure to mixtures of contaminants. Lastly, there are synergistic effects between climate change and chemical pollution. For example, climate change appears to increase the toxicity of metals and increase the frequency of toxic algal bloom and pathogenic bacteria outbreaks as a result of rising temperatures and extreme precipitation events (Cabral et al. 2019).

Despite the severity of sea pollution and growing recognition of its effects on health, significant uncertainties remain. Because of these knowledge gaps, the impacts of sea pollution on human health and well-being are surely underestimated. Therefore, in order to protect the public from exposure to such harm, decision-makers should adopt a precautionary approach and control pollution in a coordinated manner because pollution is transboundary, and all of the health impacts of sea pollution fall disproportionately on vulnerable populations of southern and eastern Mediterranean countries.

As a concluding remark, the Mediterranean is faced with the complex health impacts of climate change, ranging from waterborne diseases to heat-induced illnesses. The need for a comprehensive, precautionary approach to mitigate these risks is clear. Tackling the environmental determinants of health through coordinated pollution control and adaptation strategies will be important in protecting the well-being of the region's most vulnerable communities in the face of an unpredictable climate future.

3.5 Impacts on natural systems

Coastal natural systems such as wetlands and deltaic systems, in particular, are under the direct and indirect impacts caused by high population density and related human activities. Among these activities, those that are most significant and the most harmful include expanded agriculture to the detriment of coastal wetlands and coastal urbanisation which have generated adverse impacts on hydrological fluxes and the salinity of surface water, overexploitation of coastal groundwater which in turn have caused and are still adversely impacting ecological systems. Sea level rise due to climate change and due to coastal subsidence continue to exacerbate unfavourable conditions on Mediterranean low-lying natural systems.

3.5.1 Impacts on coastal low-lying areas, wetlands and deltaic systems

The Mediterranean wetlands occupy 2 to 3% of the land area of the Mediterranean Basin and include a diversity of ecosystems, including lagoons and salt marshes, freshwater lakes, karstic cave systems, temporary ponds, artificial wetlands such as reservoirs, Salinas, fishponds and rice paddies, small and scattered peatlands, and several large rivers with their corresponding deltas. At the same time, 30% of the region's vertebrate species depend on Mediterranean wetlands (N. G. Taylor et al. 2021), and across history, these ecosystems have contributed multiple ecosystem services to different civilizations and cultures, and to the identity and well-being of communities, making them an important component of Mediterranean social-ecological systems (Balbo et al. 2017) *(Figure 3.9).*

Since 1900, 50% of wetlands have been lost, with significantly high figures observed for various wetland ecosystems across the region. 73% of marshes have been drained in northern Greece since 1930, 86% of the 78 most important wetlands of France were degraded by 1994, 60% of primary wetland area has been lost in Spain; and 84% of the wetland area in the Medjerda Basin, Tunisia, was lost during the 20th century (Balbo et al. 2017). While this trend may have slowed down in recent years

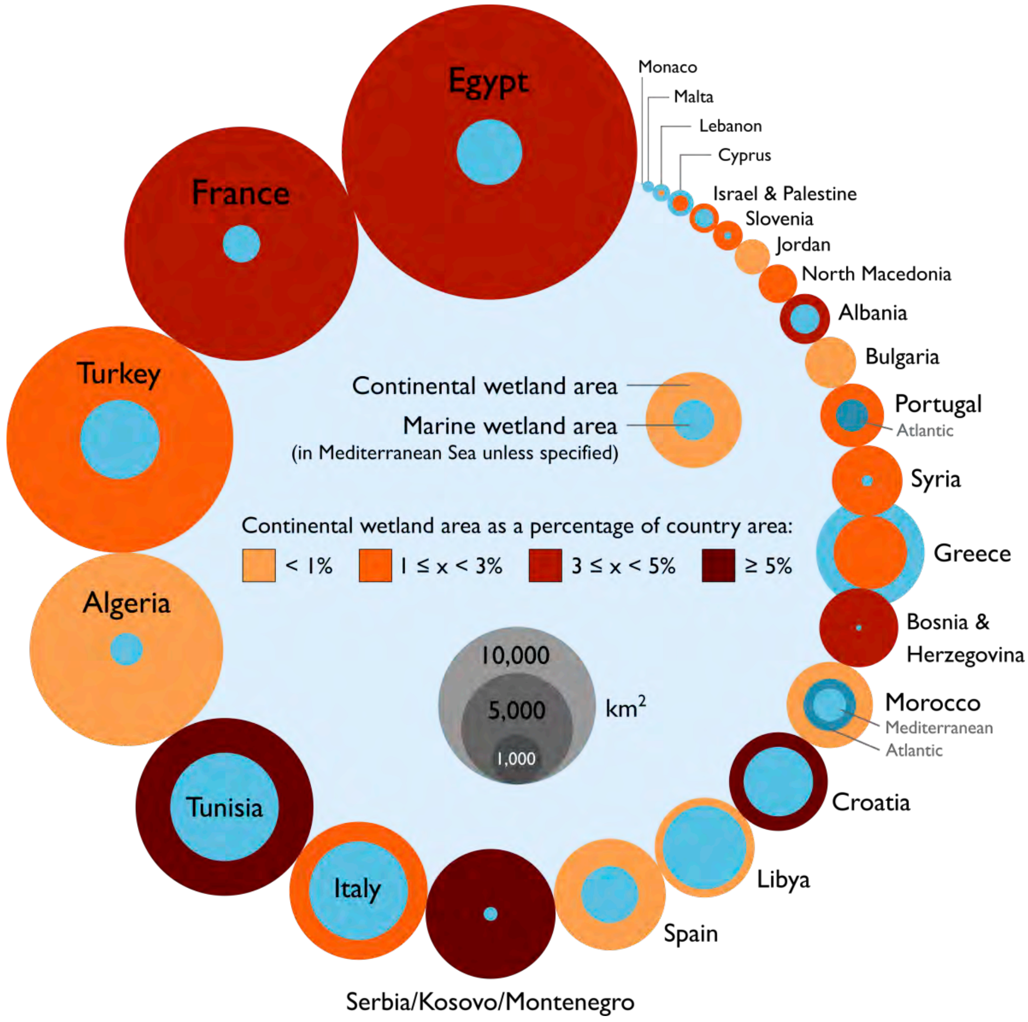


Figure 3.9 | Overview of the extent of Mediterranean wetlands. The area of each circle is proportional to the wetland area. Yellow-orange-red circles represent continental surface wetlands; shading indicates the percentage of each country covered by wetlands. Blue circles represent marine wetlands (< 6 m water depth at low tide) on the Mediterranean coast of each country, plus Atlantic coasts for Morocco and Portugal. Data from Perennou et al. (2012) and MWO (2018), as presented in N. G. Taylor et al. (2021).

(Balbo et al. 2017), the level of protection varies, and recent research indicates that wetland sites in the southeastern Mediterranean combined low or no protection with the highest increases in temperature and losses in natural habitats (Leberger et al. 2020). In the Mediterranean, the largest coastal wetlands are found in delta areas, such as those of the Nile (Egypt), Rhône (France), Po (Italy) and Ebro (Spain) rivers. Delta areas are vulnerable to human modification and climate change, with sea-level rise considered a key threat causing increased flooding, coastal erosion, extreme events, salinity intrusion and habitat degradation.

Cultural uses of coastal wetlands, and particularly the expansion of irrigated agricultural areas and urban development, have led to significant and complex changes to Mediterranean coastal wetlands, with impacts on hydrological fluxes and the salinity of surface water, in turn affecting ecological communities. For example, in the case of Doñana wetlands, situated within the delta of the Guadalquivir River (south-west Spain), 80% of its original marsh surface area has been converted, mainly for agriculture. Agricultural runoff, intense urban development, inadequate wastewater treatment, and extensive hydrological modifications

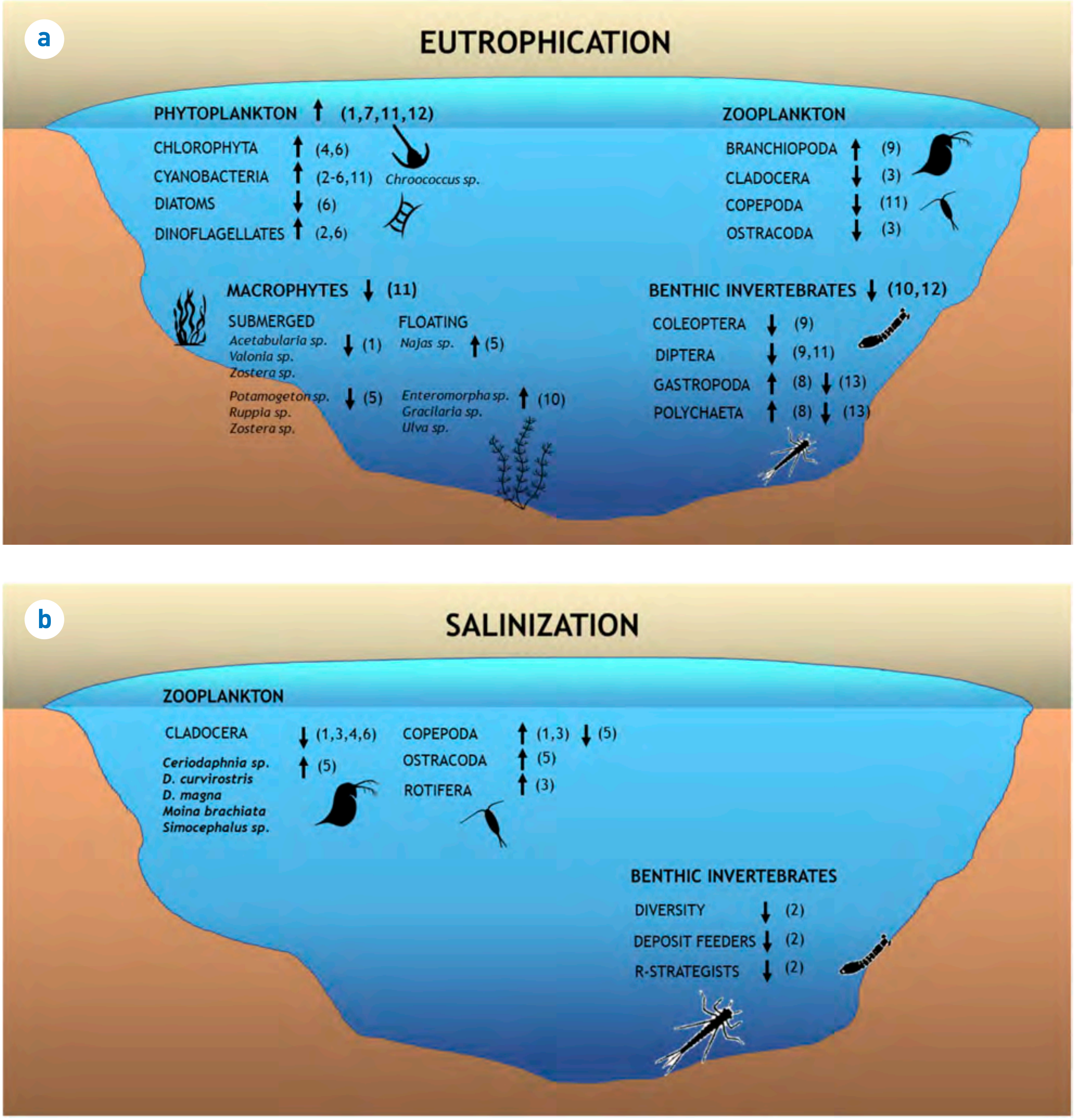


Figure 3.10 | Scheme showing the influence of eutrophication and salinisation on different aquatic organisms of Mediterranean coastal wetlands. Arrows indicate an abundance increase or decrease caused by (a) eutrophication and (b) salinisation. The summary is based on the reviewed studies by Martínez-Megías and Rico (2022).

have led to high nutrient loading in the remaining wetlands (Green et al. 2017). Furthermore, water management associated with the expansion of coastal tourism, combined with the effect of climate change, could lead to reductions in groundwater storage and saltwater intrusion (Maneas et al. 2019).

Rising temperatures will *likely* increase evapotranspiration rates, which, combined with reduced rainfall will enhance plant water stress and increase water demands for crop irrigation. These conditions will influence the water biota by favouring species more tolerant to drought (*high agreement, medium evidence).* Macroinvertebrate communities

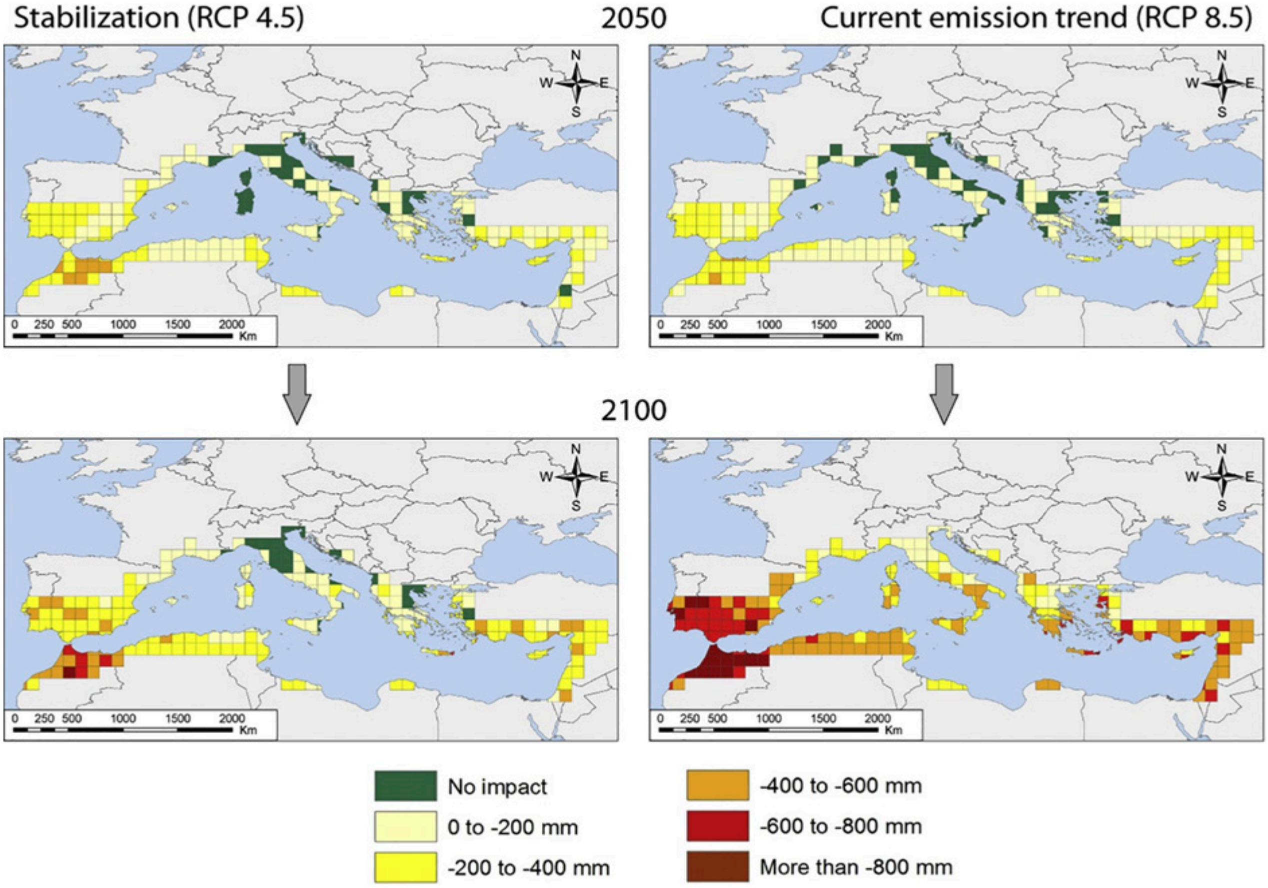


Figure 3.11 | Contemporary (1981–2013) annual water balance (precipitation minus evapotranspiration) for each of the 229 Mediterranean localities under constant flood conditions. The thirteen localities for which seasonal flooding patterns could not be simulated under the current climate conditions are shown in grey. Source: Lefebvre et al. (2019).

are moderately resilient to salinity increases but salinity increases to polyhaline conditions cause drastic community simplifications in terms of functional evenness, and loss of biodiversity (Muresan et al. 2020). On the other hand, temperature and salinity increases, combined with insecticide exposure, contributed to a decline in zooplankton diversity, but increased temperature was associated with increased abundance while increased salinity was associated with reduced abundance across all zooplankton groups (*Figure 3.10*) (Vilas-Boas et al. 2021; Martínez-Megías and Rico 2022). Excessive nutrient loading also leads to changes in the biotic community and may lead to dominance by blue-green algae (cyanobacteria) or floating plants, triggering losses in biodiversity and ecosystem services. Eutrophication and higher temperatures work in combination to reduce levels of dissolved oxygen, causing lethal and non-lethal effects (Green et al. 2017).

Decreases in mean precipitation and precipitation variability during the dry season are *likely* to have profound effects on Mediterranean wetlands, however, the impact of climate change on wetlands will be closely tied to changes in water deficits, which are currently heterogeneous across the Mediterranean region *(Figure 3.11).* In a study investigating how climate change will affect the values and functions of Mediterranean seasonally-flooded wetlands with emergent vegetation, using future projections of the relevant climate variables under two Representative Concentration Pathway scenarios assuming stabilisation (RCP4.5) or increase (RCP8.5) in greenhouse gas emissions, increases in water deficits in most localities around 2050 under both RCP scenarios were recorded. Simulations performed under current conditions show that 97% of localities could have wetland habitats in a good state. By 2050, however, this proportion would decrease to 81% and 68% under the RCP4.5 and RCP8.5 scenarios, decreasing further to 52% and 27% by 2100. Results from this study indicate that wetlands can persist with up to a 400 mm decrease in annual precipitation, with this resilience being attributed to the semi-permanent character of wetlands and their capacity to function as reservoirs. Countries at the highest risk of wetland degradation and loss were identified as Algeria, Morocco, Portugal, and Spain (Lefebvre et al. 2019).

A rise in sea level of 0.16 m (RCP8.5) in the short term (2026–2045) and 0.79 m (RCP8.5) by the end of the 21st century (2081–2100) are predicted by the CMIP5 models. On the other hand, the extreme proposed scenarios indicate rises from 1.35 m to 1.92 m by the end of the 21st century. The IPCC scenarios will lead to the loss of coastal wetlands *(high agreement, robust evidence).* For example, the IPCC scenarios are expected to lead to the loss of 96 km² of the Júcar River Basin District in Spain, with wetlands having high ecological value and protected under the RAMSAR convention[44] and as part of the Natura 2000 Network[45]. The high-end scenarios significantly increased the areas at high risk to 142 km² and impacted an urban area of 27 km² (Estrela-Segrelles et al. 2021). Sea level rise interacts with other climate factors such as temperature rise and frequency of storms, and non-climate drivers such as the lack of sedimentary contributions due to the regulation of riverbeds, the overexploitation of water resources and coastal aquifers, and associated coastal erosion and seawater intrusion *(high agreement; limited evidence)* (Maneas et al. 2019; Estrela-Segrelles et al. 2021; Ferrarini et al. 2021; Rodríguez-Santalla and Navarro 2021).

3.5.2 Impacts on coastal ecosystems

Coastal ecosystems and people are facing significant risks from sea-level rise which are susceptible to increase tenfold before 2100 if no adaptation options and mitigation scenarios have been taken into consideration and implemented in accordance with the Paris Agreement. With extreme emission scenarios that do not limit warming to 1.5°C, the rising sea level will increase the risk of coastal erosion and coastal land submergence, loss of coastal habitat, and ecosystem loss. It will also cause groundwater salinisation, compromising coastal ecosystems and livelihoods. The Mediterranean is known for its micro-tidal nature, which would increase the susceptibility to coastal hazards related to climate change. The coastal zone refers to the physical region from the edge of the continental shelf to the intertidal and near-shore terrestrial area. It includes a wide range of near-shore terrestrial, intertidal, benthic, and pelagic ecosystems with some main categories being estuaries, coastal marshes, seagrass, and benthic systems (X. Yang 2008; Oppenheimer et al. 2019). Coastal ecosystems are highly impacted by a combination of conditions, including sea level rise, coastal erosion, acidification, and other climate-related ocean changes. They are also experiencing some adverse effects derived from urbanization and human activities on the ocean and land. The Mediterranean Basin is experiencing continuous changes in environmental conditions, creating major challenges, and introducing new vulnerabilities to its natural and human systems. Coastal ecosystems could progressively lose their ability to adapt to climate-induced changes and consequently their services, including acting as coastal protective barriers (Oppenheimer et al. 2019). Loss of breeding substrate, including mostly coastal habitats such as sandy beaches, can reduce the available nesting or pupping habitat for land-breeding marine animals and seabirds.

Coastal erosion is a major cause of the loss of ecosystem services provided by beaches, as most habitats in coastal areas could be affected, degraded, or disappear as erosion progresses (Paprotny et al. 2021). In a study to evaluate the effect of coastal erosion along the northern Mediterranean Basin (the European coast) for ecosystem services under the RCP4.5 and RCP8.5 scenarios estimates a 5% decline in services by 2100 under RCP8.5 showing high spatial variability with the largest estimated declines in the eastern Mediterranean. The value of ecosystem services declined by €323 million between 2000 and 2018. The majority of the coastal services decline was mainly attributed to forest contraction and intense agriculture, which was partially offset

---

[44] https://www.ramsar.org/

[45] https://environment.ec.europa.eu/topics/nature-and-biodiversity/natura-2000_en

by the expansion of wetlands, mainly salt marshes. Salt marshes are among the most climate-affected coastal habitat, although they are well-known for wave attenuation and for their role in reducing erosion and flooding (Kirwan and Guntenspergen 2010; Temmerman et al. 2012, 2023; Arkema et al. 2013; Vuik et al. 2016). Erosion-destroyed salt marshes or sand dunes along coastlines are more endangered than others. Saline bodies, estuaries, inland marshes, and natural grasslands would also be among the most affected habitats.

Coastal erosion has been affecting most of the Mediterranean coastal zones with growing intensity along the European coasts due to climate change (Terefenko et al. 2018a, 2018b, 2019; Paprotny et al. 2021). The Mediterranean hotspots of erosion impacts are discussed in detail in *Section 3.2.2* of this report. The major losses were in beaches, sand, and dunes and the most affected countries in the Mediterranean Basin are Albania, Greece and France and could be among those to lose the largest share of their coastal ecosystem services. Erosion could also create a new challenge with regard to flooding, affecting coastal lagoons by causing beach loss and changing their characteristics and services. Climate-induced saltwater intrusions could also vigorously affect many other coastal habitats (Barlow and Reichard 2010).

Annual damage is projected to rise by 90 to 900 times if future climate change scenarios and socio-economic trends are combined. Rising sea levels increase storm wave frequency, and reduce the sediment supply to the coast, while anthropogenic degradation, and coastal transformation could lead to an irretrievable loss of ecosystem services (Barbier et al. 2011; Ranasinghe 2016).

With regards to systems and habitats close to shore, it is still uncertain how anthropogenic CO_2 inputs and the resulting rapid acidification could affect coastal systems, mainly due to the lack of data. However, some research in the Mediterranean has examined changes in ocean chemistry and how it affects marine and coastal ecosystems, as well as socio-economic sectors. These studies have identified tourism and recreation, red coral extraction, and fisheries as the sectors more *likely* to be affected (Rodrigues et al. 2013; Peled et al. 2018; Hassoun et al. 2022). Ramajo et al. (2019) and others have suggested treating the acidification problem with seagrasses which may provide 'refugia' from ocean acidification for associated calcifying organisms as their photosynthetic activity can raise pH above the thresholds for impacts on calcification and/or limit the time spent below some critical pH thresholds. It has been proven that seagrass covers are effective in decreasing runoff and reducing soil losses particularly during the summer and under intense events (Ramajo et al. 2019).

Any changes in sediment supply, industrial development, and urban processes can enhance the vulnerability of coastal sandy beaches and saltmarshes to sea-level rise. Mediterranean aquifer systems and other water bodies are experiencing high exploitation levels with increased water demand and salinisation. In addition, growing population increases the human demand for water, and this puts additional pressure on water resources and increases the severity of water scarcity dramatically (Iglesias and Garrote 2018; Bond et al. 2019). The long-term changes induced by climate, particularly marine heatwaves, are significantly affecting marine ecosystems, causing mortality or bleaching of coral and mass mortalities of other species leading to a decline of kelp forests, loss of seagrass-meadow habitats, invasion of new species, and acute changes in the community structure of several marine ecosystems and increased carbon emissions. Harmful blooms of algal species and other waterborne diseases have increased as a consequence of climate change and this disturbance threatens human health and livelihoods of coastal communities (see *Chapter 2*). However, most of these risks are still uncertain at transboundary and regional levels, which may pose major challenge for cooperation among Mediterranean countries (Reimann et al. 2018b; Vafeidis et al. 2020).

In conclusion, the Mediterranean natural system is facing continued adverse impacts leading to increased vulnerabilities to the environment and humans. Coastal ecosystems that act as protective barriers (e.g. sandy beaches, marshlands, sand dunes) and mitigate climate change impacts are under severe risks *(high confidence)*. It is *very likely* that the consequence may result in progressive loss of ecosystem services or loss of their ability to adapt to climate-induced changes. Bearing in mind that the prosperity of the Mediterranean population relies on the health of natural systems, proactive planning is essential in mitigating the increasing risks and hazards associated with climate change.

3.6 Final remarks

Regardless of the underlying causes triggering coastal hazards in the Mediterranean Basin, their extent, and their cumulative action under current conditions on existing assets and values along the coastline designate it as a high-risk area. Despite inherent uncertainties, anticipated changes in these hazards will escalate risks to people, infrastructure, and natural resources. While some risks are localised, many transcend national borders, underscoring the necessity for robust transboundary and regional cooperation among Mediterranean countries to effectively address these significant challenges.

References

Abd-Elmabod S. K., Muñoz-Rojas M., Jordán A., Anaya-Romero M., Phillips J. D., Jones L., Zhang Z., Pereira P., Fleskens L., Van Der Ploeg M., and De La Rosa D. (2020). Climate change impacts on agricultural suitability and yield reduction in a Mediterranean region. *Geoderma*, *374*, 114453. doi: 10.1016/j.geoderma.2020.114453

Abella A., Ria M., and Mancusi C. (2010). Assessment of the status of the coastal groundfish assemblage exploited by the Viareggio fleet (Southern Ligurian Sea). *Scientia Marina*, *74*(4), 793–805. doi: 10.3989/scimar.2010.74n4793

Abo El Nile M. (2017). Potential Impact of Climate Change on Beach Tourism in MENA Countries: A Survey Based Study. *Journal of Association of Arab Universities for Tourism and Hospitality*, *14*(1), 111–126. doi: 10.21608/jaauth.2017.50040

Abutaleb K. A. A., Mohammed A. H. E.-S., and Ahmed M. H. M. (2018). Climate Change Impacts, Vulnerabilities and Adaption Measures for Egypt's Nile Delta. *Earth Systems and Environment*, *2*(2), 183–192. doi: 10.1007/s41748-018-0047-9

Agoubi B. (2021). A review: saltwater intrusion in North Africa's coastal areas—current state and future challenges. *Environmental Science and Pollution Research*, *28*(14), 17029–17043. doi: 10.1007/s11356-021-12741-z

Aguilera E., Díaz-Gaona C., García-Laureano R., Reyes-Palomo C., Guzmán G. I., Ortolani L., Sánchez-Rodríguez M., and Rodríguez-Estévez V. (2020). Agroecology for adaptation to climate change and resource depletion in the Mediterranean region. A review. *Agricultural Systems*, *181*, 102809. doi: 10.1016/j.agsy.2020.102809

Albouy C., Guilhaumon F., Leprieur F., Ben Rais Lasram F., Somot S., Aznar R., Velez L., Le Loc'h F., and Mouillot D. (2013). Projected climate change and the changing biogeography of coastal Mediterranean fishes. *Journal of Biogeography*, *40*(3), 534–547. doi: 10.1111/jbi.12013

Alfieri L., Burek P., Feyen L., and Forzieri G. (2015). Global warming increases the frequency of river floods in Europe. *Hydrology and Earth System Sciences*, *19*(5), 2247–2260. doi: 10.5194/hess-19-2247-2015

Ali E., Cramer W., Carnicer J., Georgopoulou E., Hilmi N. J. M., Le Cozannet G., and Lionello P. (2022). Cross-Chapter Paper 4: Mediterranean Region. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2233–2272. doi: 10.1017/9781009325844.021

Al-Jawaldeh A., Nabhani M., Taktouk M., and Nasreddine L. (2022). Climate Change and Nutrition: Implications for the Eastern Mediterranean Region. *International Journal of Environmental Research and Public Health*, *19*(24), 17086. doi: 10.3390/ijerph192417086

Alkhawaga A., Zeidan B., and Elshemy M. (2022). Climate change impacts on water security elements of Kafr El-Sheikh governorate, Egypt. *Agricultural Water Management*, *259*, 107217. doi: 10.1016/j.agwat.2021.107217

Almar R., Ranasinghe R., Bergsma E. W. J., Diaz H., Melet A., Papa F., Vousdoukas M., Athanasiou P., Dada O., Almeida L. P., and Kestenare E. (2021). A global analysis of extreme coastal water levels with implications for potential coastal overtopping. *Nature Communications*, *12*(1), 3775. doi: 10.1038/s41467-021-24008-9

Amarouche K., Akpınar A., Çakmak R. E., Houma F., and Bachari N. E. I. (2020). Assessment of storm events along the Algiers coast and their potential impacts. *Ocean Engineering*, *210*, 107432. doi: 10.1016/j.oceaneng.2020.107432

Amarouche K., Akpınar A., and Semedo A. (2022). Wave storm events in the Western Mediterranean Sea over four decades. *Ocean Modelling*, *170*, 101933. doi: 10.1016/j.ocemod.2021.101933

Amelung B., and Viner D. (2006). Mediterranean Tourism: Exploring the Future with the Tourism Climatic Index. *Journal of Sustainable Tourism*, *14*(4), 349–366. doi: 10.2167/jost549.0

Amengual A., Homar V., Romero R., Ramis C., and Alonso S. (2014). Projections for the 21st century of the climate potential for beach-based tourism in the Mediterranean. *International Journal of Climatology*, *34*(13), 3481–3498. doi: 10.1002/joc.3922

Amores A., Marcos M., Carrió D. S., and Gómez-Pujol L. (2020). Coastal impacts of Storm Gloria (January 2020) over the north-western Mediterranean. *Natural Hazards and Earth System Sciences*, *20*(7), 1955–1968. doi: 10.5194/nhess-20-1955-2020

Amrouni O., Hzami A., and Heggy E. (2019). Photogrammetric assessment of shoreline retreat in North Africa: Anthropogenic and natural drivers. *ISPRS Journal of Photogrammetry and Remote Sensing*, *157*, 73–92. doi: 10.1016/j.isprsjprs.2019.09.001

Anfuso G., and Nachite D. (2011). Climate change and the Mediterranean southern coasts. In A. Jones & M. Phillips (Eds.), *Disappearing destinations: Climate change and future challenges for coastal tourism* (1st ed., pp. 99–110). CABI. doi: 10.1079/9781845935481.0099

Anfuso G., Pranzini E., and Vitale G. (2011). An integrated approach to coastal erosion problems in northern Tuscany (Italy): Littoral morphological evolution and cell distribution. *Geomorphology*, *129*(3–4), 204–214. doi: 10.1016/j.geomorph.2011.01.023

Antonioli F., Anzidei M., Amorosi A., Lo Presti V., Mastronuzzi G., Deiana G., De Falco G., Fontana A., Fontolan G., Lisco S., Marsico A., Moretti M., Orrù P. E., Sannino G. M., Serpelloni E., and Vecchio A. (2017). Sea-level rise and potential drowning of the Italian coastal plains: Flooding risk scenarios for 2100. *Quaternary Science Reviews*, *158*, 29–43. doi: 10.1016/j.quascirev.2016.12.021

Antonioli F., De Falco G., Lo Presti V., Moretti L., Scardino G., Anzidei M., Bonaldo D., Carniel S., Leoni G., Furlani S., Marsico A., Petitta M., Randazzo G., Scicchitano G., and Mastronuzzi G. (2020). Relative Sea-Level Rise and Potential Submersion Risk for 2100 on 16 Coastal Plains of the Mediterranean Sea. *Water*, *12*(8), 2173. doi: 10.3390/w12082173

Anzidei M., Scicchitano G., Scardino G., Bignami C., Tolomei C., Vecchio A., Serpelloni E., De Santis V., Monaco C., Milella M., Piscitelli A., and Mastronuzzi G. (2021). Relative Sea-Level Rise Scenario for 2100 along the Coast of South Eastern Sicily (Italy) by InSAR Data, Satellite Images and High-Resolution Topography. *Remote Sensing*, *13*(6), 1108. doi: 10.3390/rs13061108

Arabadzhyan A., Figini P., García C., González M. M., Lam-González Y. E., and León C. J. (2021). Climate change, coastal tourism, and impact chains – a literature review. *Current Issues in Tourism*, *24*(16), 2233–2268. doi: 10.1080/13683500.2020.1825351

Aragão G. M., López-López L., Punzón A., Guijarro E., Esteban A., García E., González-Irusta J. M., Polo J., Vivas M., and Hidalgo M. (2022). The importance of regional differences in vulnerability to climate change for demersal fisheries. *ICES Journal of Marine Science*, *79*(2), 506–518. doi: 10.1093/icesjms/fsab134

Arkema K. K., Guannel G., Verutes G., Wood S. A., Guerry A., Ruckelshaus M., Kareiva P., Lacayo M., and Silver J. M. (2013). Coastal habitats shield people and property from sea-level rise and storms. *Nature Climate Change*, *3*(10), 913–918. doi: 10.1038/nclimate1944

ARLEM (2021). *Report on Agriculture & Food Security in the context of climate change in the Mediterranean*. https://cpmr-intermed.org/download/arlem-report-on-agriculture-food-security-in-the-context-of-climate-change-in-the-mediterranean/

Armaroli C., Ciavola P., Perini L., Calabrese L., Lorito S., Valentini A., and Masina M. (2012). Critical storm thresholds for significant morphological changes and damage along the Emilia-Romagna coastline, Italy. *Geomorphology*, *143–144*, 34–51. doi: 10.1016/j.geomorph.2011.09.006

Armaroli C., and Duo E. (2018). Validation of the coastal storm risk assessment framework along the Emilia-Romagna coast. *Coastal Engineering*, *134*, 159–167. doi: 10.1016/j.coastaleng.2017.08.014

Armaroli C., Duo E., and Viavattene C. (2019). From Hazard to Consequences: Evaluation of Direct and Indirect Impacts of Flooding Along the Emilia-Romagna Coastline, Italy. *Frontiers in Earth Science*, *7*, 203. doi: 10.3389/feart.2019.00203

Arns A., Dangendorf S., Jensen J., Talke S., Bender J., and Pattiaratchi C. (2017). Sea-level rise induced amplification of coastal protection design heights. *Scientific Reports*, *7*(1), 40171. doi: 10.1038/srep40171

Atay M. U. (2015). *The Impact of Climate Change on Agricultural Production in Mediterranean Countries*. Middle East Technical University (Turkey) ProQuest Dissertations & Theses. https://hdl.handle.net/11511/25215

Attard M. (2015). The impact of global environmental change on transport in Malta. *Xjenza Online- Journal of The Malta Chamber of Scientists*, *3*(2), 141–152. doi: 10.7423/xjenza.2015.2.06

Aucelli P. P., Di Paola G., Incontri P., Rizzo A., Vilardo G., Benassai G., Buonocore B., and Pappone G. (2017). Coastal inundation risk assessment due to subsidence and sea level rise in a Mediterranean alluvial plain (Volturno coastal plain – southern Italy). *Estuarine, Coastal and Shelf Science*, *198*, 597–609. doi: 10.1016/j.ecss.2016.06.017

Ayllón D., Railsback S. F., Harvey B. C., García Quirós I., Nicola G. G., Elvira B., and Almodóvar A. (2019). Mechanistic simulations predict that thermal and hydrological effects of climate change on Mediterranean trout cannot be offset by adaptive behaviour, evolution, and increased food production. *Science of The Total Environment*, *693*, 133648. doi: 10.1016/j.scitotenv.2019.133648

Azzurro E., Smeraldo S., and D'Amen M. (2022). Spatio-temporal dynamics of exotic fish species in the Mediterranean Sea: Over a century of invasion reconstructed. *Global Change Biology*, *28*(21), 6268–6279. doi: 10.1111/gcb.16362

Babeyko A., Lorito S., Hernandez F., Lauterjung J., Løvholt F., Rudloff A., Sørensen M., Androsov A., Aniel-Quiroga I., Armigliato A., Baptista M. A., Baglione E., Basili R., Behrens J., Brizuela B., Bruni S., Cambaz D., Cantavella Nadal J., Carillho F., ... Yalciner A. (2022). Towards the new Thematic Core Service Tsunami within the EPOS Research Infrastructure. *Annals of Geophysics*, *65*(2), DM215. doi: 10.4401/ag-8762

Báez J. C., Pennino M. G., Albo-Puigserver M., Coll M., Giraldez A., and Bellido J. M. (2022). Effects of environmental conditions and jellyfish blooms on small pelagic fish and fisheries from the Western Mediterranean Sea. *Estuarine, Coastal and Shelf Science*, *264*, 107699. doi: 10.1016/j.ecss.2021.107699

Baglivo C., Congedo P. M., Murrone G., and Lezzi D. (2022). Long-term predictive energy analysis of a high-performance building in a mediterranean climate under climate change. *Energy*, *238*, 121641. doi: 10.1016/j.energy.2021.121641

Balbo A. L., Martinez-Fernández J., and Esteve-Selma M. (2017). Mediterranean wetlands: archaeology, ecology, and sustainability. *WIREs Water*, *4*(6). https://doi.org/10.1002/wat2.1238

Ballesteros C., Jiménez J. A., Valdemoro H. I., and Bosom E. (2018). Erosion consequences on beach functions along the Maresme coast (NW Mediterranean, Spain). *Natural Hazards*, *90*(1), 173–195. doi: 10.1007/s11069-017-3038-5

Balzan M. V, Hassoun A. E. R., Aroua N., Baldy V., Dagher M. B., Branquinho C., Dutay J.-C., Bour M. El, Médail F., Mojtahid M., Morán-Ordóñez A., Roggero P. P., Heras S. R., Schatz B., Vogiatzakis I. N., Zaimes G. N., and Ziveri P. (2020). Chapter 4: Ecosystems. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report.* Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, pp. 323-468. doi: 10.5281/zenodo.7101089

Barbier E. B., Hacker S. D., Kennedy C., Koch E. W., Stier A. C., and Silliman B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, *81*(2), 169–193. doi:10.1890/10-1510.1

Barhoumi B., Metian M., Zaghden H., Derouiche A., Ben Ameur W., Ben Hassine S., Oberhaensli F., Mora J., Mourgkogiannis N., Al-Rawabdeh A. M., Chouba L., Alonso-Hernández C. M., Karapanagioti H. K., Driss M. R., Mliki A., and Touil S. (2023). Microplastic-sorbed persistent organic pollutants in coastal Mediterranean Sea areas of Tunisia. *Environmental Science: Processes & Impacts*, *25*(8), 1347–1364. doi: 10.1039/d3em00169e

Barlow P. M., and Reichard E. G. (2010). Saltwater intrusion in coastal regions of North America. *Hydrogeology Journal*, *18*(1), 247–260. doi: 10.1007/s10040-009-0514-3

Basso L., Rizzo L., Marzano M., Intranuovo M., Fosso B., Pesole G., Piraino S., and Stabili L. (2019). Jellyfish summer outbreaks as bacterial vectors and potential hazards for marine animals and humans health? The case of Rhizostoma pulmo (Scyphozoa, Cnidaria). *Science of The Total Environment*, *692*, 305–318. doi: 10.1016/j.scitotenv.2019.07.155

Bazzana D., Comincioli N., El Khoury C., Nardi F., and Vergalli S. (2023). WEF Nexus Policy Review of Four Mediterranean Countries. *Land*, *12*(2), 473. doi: 10.3390/land12020473

Beiras R. (2018). *Marine Pollution: Sources, Fate and Effects of Pollutants in Coastal Ecosystems*. Elsevier. doi: 10.1016/c2017-0-00260-4

Bell J. D., Allain V., Sen Gupta A., Johnson J., Hampton J., Hobday A., Lehodey P., Lenton A., Morre B., Pratchett M., Senina I., Smith N., and Williams P. (2018). Climate change impacts, vulnerabilities and adaptations: Western and Central Pacific Ocean marine fisheries. In M. Barange, T. Bahri, K. Cochranes, S. Funge-Smith, & F. Poulain (Eds.), *Impacts of climate change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options*. FAO Fisheries and Aquaculture Technical Paper, No. 627. Rome, FAO. pp. 305-324. https://openknowledge.fao.org/handle/20.500.14283/i9705en

Ben Hamed S., Guardiola F., Cuesta A., Martínez S., Martínez-Sánchez M. J., Pérez-Sirvent C., and Esteban M. Á. (2017). Head kidney, liver and skin histopathology and gene expression in gilthead seabream (Sparus aurata L.) exposed to highly polluted marine sediments from Portman Bay (Spain). *Chemosphere*, *174*, 563–571. doi: 10.1016/j.chemosphere.2017.02.009

Berghuijs W. R., Harrigan S., Molnar P., Slater L. J., and Kirchner J. W. (2019). The Relative Importance of Different Flood-Generating Mechanisms Across Europe. *Water Resources Research*, *55*(6), 4582–4593. doi: 10.1029/2019wr024841

Berke S. K. (2010). Functional groups of ecosystem engineers: A proposed classification with comments on current issues. *Integrative and Comparative Biology*, *50*(2), 147–157. doi: 10.1093/icb/icq077

Besset M., Anthony E. J., and Bouchette F. (2019). Multi-decadal variations in delta shorelines and their relationship to river sediment supply: An assessment and review. *Earth-Science Reviews*, *193*, 199–219. doi: 10.1016/j.earscirev.2019.04.018

Bevacqua E., Maraun D., Vousdoukas M. I., Voukouvalas E., Vrac M., Mentaschi L., and Widmann M. (2019). Higher probability of compound flooding from precipitation and storm surge in Europe under anthropogenic climate change. *Science Advances*, *5*(9), eaaw5531. doi: 10.1126/sciadv.aaw5531

Björklund H., Bondestam J., and Bylund G. (1990). Residues of oxytetracycline in wild fish and sediments from fish farms. *Aquaculture*, *86*(4), 359–367. doi: 10.1016/0044-8486(90)90324-g

Blackburn T. M., Bellard C., and Ricciardi A. (2019). Alien versus native species as drivers of recent extinctions. *Frontiers in Ecology and the Environment*, *17*(4), 203–207. doi: 10.1002/fee.2020

Blöschl G., Hall J., Viglione A., Perdigão R. A. P., Parajka J., Merz B., Lun D., Arheimer B., Aronica G. T., Bilibashi A., Boháč M., Bonacci O., Borga M., Čanjevac I., Castellarin A., Chirico G. B., Claps P., Frolova N., Ganora D., ... Živković N. (2019). Changing climate both increases and decreases European river floods. *Nature*, *573*(7772), 108–111. doi: 10.1038/s41586-019-1495-6

Boero F., Bouillon J., Gravili C., Miglietta M., Parsons T., and Piraino S. (2008). Gelatinous plankton: irregularities rule the world (sometimes). *Marine Ecology Progress Series*, *356*, 299–310. doi: 10.3354/meps07368

Bonazza A. (2022). Sustainable heritage and climate change. In K. Fouseki, M. Cassar, G. Dreyfuss, & K. Ang Kah Eng (Eds.), *Routledge Handbook of Sustainable Heritage,*. Routledge: London, United Kingdom, pp. 263-271. doi: 10.4324/9781003038955

Bonazza A., Messina P., Sabbioni C., Grossi C. M., and Brimblecombe P. (2009a). Mapping the impact of climate change on surface recession of carbonate buildings in Europe. *Science of The Total Environment*, *407*(6), 2039–2050. doi: 10.1016/j.scitotenv.2008.10.067

Bonazza A., Sabbioni C., Messina P., Guaraldi C., and De Nuntiis P. (2009b). Climate change impact: Mapping thermal stress on Carrara marble in Europe. *Science of The Total Environment*, *407*(15), 4506–4512. doi: 10.1016/j.scitotenv.2009.04.008

Bonazza A., Sardella A., Kaiser A., Cacciotti R., De Nuntiis P., Hanus C., Maxwell I., Drdácký T., and Drdácký M. (2021). Safeguarding cultural heritage from climate change related hydrometeorological hazards in Central Europe. *International Journal of Disaster Risk Reduction*, *63*, 102455. doi: 10.1016/j.ijdrr.2021.102455

Bond N. R., Burrows R. M., Kennard M. J., and Bunn S. E. (2019). Water Scarcity as a Driver of Multiple Stressor Effects. In *Multiple Stressors in River Ecosystems* (pp. 111–129). Elsevier. doi: 10.1016/b978-0-12-811713-2.00006-6

Bosello F., Eboli F., and Pierfederici R. (2013). Climate Change Impacts: A New Integrated Assessment. *SSRN Electronic Journal*. doi: 10.2139/ssrn.2491657

Bosello F., Roson R., and Tol R. S. J. (2007). Economy-wide estimates of the implications of climate change: Sea level rise. *Environmental and Resource Economics*, *37*(3), 549–571. doi: 10.1007/s10640-006-9048-5

Bouregaa T. (2022). Climate change projections for Algeria: the 2030 water sector development strategy. *Foresight*, *25*, 516–534. doi: 10.1108/fs-05-2021-0110

Bozoglu M., Başer U., Eroglu N. A., and Topuz B. K. (2019). Impacts of Climate Change on Turkish Agriculture. *Journal of International Environmental Application and Science*, *14*(3), 97–103. https://dergipark.org.tr/en/pub/jieas/issue/48886/560710

Brander K. M. (2007). Global fish production and climate change. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(50), 19709–19714. doi: 10.1073/pnas.0702059104

Bregaglio S., Hossard L., Cappelli G., Resmond R., Bocchi S., Barbier J.-M., Ruget F., and Delmotte S. (2017). Identifying trends and associated uncertainties in potential rice production under climate change in Mediterranean areas. *Agricultural and Forest Meteorology*, *237–238*, 219–232. doi: 10.1016/j.agrformet.2017.02.015

Brouziyne Y., Abouabdillah A., Hirich A., Bouabid R., Zaaboul R., and Benaabidate L. (2018). Modeling sustainable adaptation strategies toward a climate-smart agriculture in a Mediterranean watershed under projected climate change scenarios. *Agricultural Systems*, *162*, 154–163. doi: 10.1016/j.agsy.2018.01.024

Cabral H., Fonseca V., Sousa T., and Leal M. C. (2019). *Synergistic Effects of Climate Change and Marine Pollution: An Overlooked Interaction in Coastal and Estuarine Areas*. *16*(15), 2737. doi: 10.3390/ijerph16152737

Caiola N., and Sostoa A. (2005). Possible reasons for the decline of two native toothcarps in the Iberian Peninsula: evidence of competition with the introduced Eastern mosquitofish. *Journal of Applied Ichthyology*, *21*(4), 358–363. doi: 10.1111/j.1439-0426.2005.00684.x

Camacho C., Negro J. J., Elmberg J., Fox A. D., Nagy S., Pain D. J., and Green A. J. (2022). Groundwater extraction poses extreme threat to Doñana World Heritage Site. *Nature Ecology & Evolution*, *6*(6), 654–655. doi: 10.1038/s41559-022-01763-6

Cammarano D., Ceccarelli S., Grando S., Romagosa I., Benbelkacem A., Akar T., Al-Yassin A., Pecchioni N., Francia E., and Ronga D. (2019). The impact of climate change on barley yield in the Mediterranean basin. *European Journal of Agronomy*, *106*, 1–11. doi: 10.1016/j.eja.2019.03.002

Camuffo D. (2019). European Standards Concerning Microclimate for Cultural Heritage and Its Measurement. In *Microclimate for Cultural Heritage* (pp. 343–358). Elsevier. doi: 10.1016/b978-0-444-64106-9.00015-8

Camuffo D., Leissner J., Bertolin C., Antretter F., Winkler M., Kotova L., Mikolajewicz U., Jacob D. J., Ashley-Smith J., Brostrom T., Schellen H. L., and van Schijndel A. W. M. (2015). Outdoor indoor climate relationships for cultural heritage. In *Keynote lecture at the UNESCO Conference, 7-9 July 2015, Paris, France* (p. 1). https://research.tue.nl/en/publications/outdoor-indoor-climate-relationships-for-cultural-heritage

Camus P., Haigh I. D., Nasr A. A., Wahl T., Darby S. E., and Nicholls R. J. (2021). Regional analysis of multivariate compound coastal flooding potential around Europe and environs: Sensitivity analysis and spatial patterns. *Natural Hazards and Earth System Sciences*, *21*(7), 2021–2040. doi: 10.5194/nhess-21-2021-2021

Canals Artigas, M., & Miranda Canals, J. (Eds.). (2020). *Sobre el temporal Gloria (19-23.01.20), els seus efectes sobre el país i el que se'n deriva : Report de Resposta Ràpida (R3). – Primera edició*. https://upcommons.upc.edu/bitstream/handle/2117/335525/30363763.pdf?sequence=1

Cannas R. (2018). Case Study Italy: The tourism management of climate change in the Mediterranean region: adaptation strategies in Sardinia and Sicily. In A. Jones & M. Phillips (Eds.), *Global climate change and coastal tourism: recognizing problems, managing solutions and future expectations* (1st ed., pp. 111–124). CABI. doi: 10.1079/9781780648439.0111

Capone R., Berjan, S., El Bilali, H., Debs, P., & Allahyari, M. S. (2020). Environmental implications of global food loss and waste with a glimpse on the Mediterranean region. *International Food Research Journal, 27*(6), 988-1000.

Cardinale M., and Scarcella G. (2017). Mediterranean sea: A failure of the European fisheries management system. *Frontiers in Marine Science*, *4*(MAR), 231348. doi: 10.3389/fmars.2017.00072

Carosi A., Padula R., Ghetti L., and Lorenzoni M. (2019). Endemic Freshwater Fish Range Shifts Related to Global Climate Changes: A Long-Term Study Provides Some Observational Evidence for the Mediterranean Area. *Water 2019, Vol. 11, Page 2349*, *11*(11), 2349. doi: 10.3390/w11112349

Carreño A., and Lloret J. (2021). Environmental impacts of increasing leisure boating activity in Mediterranean coastal waters. *Ocean & Coastal Management*, *209*, 105693. doi: 10.1016/j.ocecoaman.2021.105693

Casas-Prat M., McInnes K. L., Hemer M. A., and Sierra J. P. (2016). Future wave-driven coastal sediment transport along the Catalan coast (NW Mediterranean). *Regional Environmental Change*, *16*(6), 1739–1750. doi: 10.1007/s10113-015-0923-x

Casas-Prat M., and Sierra J. P. (2012). Trend analysis of wave direction and associated impacts on the Catalan coast. *Climatic Change*, *115*(3–4), 667–691. doi: 10.1007/s10584-012-0466-9

CEDARE. (2014). *Libya Water Sector M&E Rapid Assessment Report. Monitoring and Evaluation for Water in North Africa (MEWINA) project, Water Resources Management Program*. CEDARE. https://web.cedare.org/wp-content/uploads/2005/05/North-Africa-Regional-Water-Sector-Monitoring-and-Evaluation-Rapid-Assessment-Report.pdf

Chaves M. de J. S., Barbosa S. C., de Melo Malinowski M., Volpato D., Castro Í. B., dos Santos Franco T. C. R., and Primel E. G. (2020). Pharmaceuticals and personal care products in a Brazilian wetland of international importance: Occurrence and environmental risk assessment. *Science of the Total Environment*, *734*, 139374. doi: 10.1016/j.scitotenv.2020.139374

Chelsky A., Pitt K. A., Ferguson A. J. P., Bennett W. W., Teasdale P. R., and Welsh D. T. (2016). Decomposition of jellyfish carrion in situ: Short-term impacts on infauna, benthic nutrient fluxes and sediment redox conditions. *Science of The Total Environment*, *566–567*, 929–937. doi: 10.1016/j.scitotenv.2016.05.011

Chen C.-C., McCarl B., and Chang C.-C. (2012). Climate change, sea level rise and rice: global market implications. *Climatic Change*, *110*(3–4), 543–560. doi: 10.1007/s10584-011-0074-0

Chen H., Jing L., Teng Y., and Wang J. (2018). Characterization of antibiotics in a large-scale river system of China: occurrence pattern, spatiotemporal distribution and environmental risks. *Science of the Total Environment*, *618*, 409–418. doi: 10.1016/j.scitotenv.2017.11.054

Chenoweth J., Hadjinicolaou P., Bruggeman A., Lelieveld J., Levin Z., Lange M. A., Xoplaki E., and Hadjikakou M. (2011). Impact of climate change on the water resources of the eastern Mediterranean and Middle East region: Modeled 21st century changes and implications. *Water Resources Research*, *47*(6), 6506. doi: 10.1029/2010wr010269

Cherif S., Doblas-Miranda E., Lionello P., Borrego C., Giorgi F., Iglesias A., Jebari S., Mahmoudi E., Moriondo M., Pringault O., Rilov G., Somot S., Tsikliras A., Vila M., and Zittis G. (2020). Drivers of change. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental Change in the Mediterranean Basin–Current Situation and Risks for the Future. First Mediterranean Assessment Report.* Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, pp. 59-180. doi: 10.5281/zenodo.7100601

Christodoulou A., Christidis P., and Demirel H. (2019). Sea-level rise in ports: a wider focus on impacts. *Maritime Economics & Logistics*, *21*(4), 482–496. doi: 10.1057/s41278-018-0114-z

CIESM (2011). Marine Geohazards in the Mediterranean: an overview. In F. Briand (Ed.), *Marine geo-hazards in the Mediterranean. N° 42 in CIESM Workshop Monographs*. CIESM, Monaco, 192 pp. https://www.researchgate.net/publication/272164711_Marine_Geohazards_in_the_Mediterranean_an_overview

Ciscar J.-C., Iglesias A., Feyen L., Szabó L., Van Regemorter D., Amelung B., Nicholls R., Watkiss P., Christensen O. B., Dankers R., Garrote L., Goodess C. M., Hunt A., Moreno A., Richards J., and Soria A. (2011). Physical and economic consequences of climate change in Europe. *Proceedings of the National Academy of Sciences*, *108*(7), 2678–2683. doi: 10.1073/pnas.1011612108

Colloca F., Scarcella G., and Libralato S. (2017). Recent Trends and Impacts of Fisheries Exploitation on Mediterranean Stocks and Ecosystems. *Frontiers in Marine Science*, *4*, 244. doi: 10.3389/fmars.2017.00244

Compa M., Alomar C., Wilcox C., van Sebille E., Lebreton L., Hardesty B. D., and Deudero S. (2019). Risk assessment of plastic pollution on marine diversity in the Mediterranean Sea. *Science of The Total Environment*, *678*, 188–196. doi: 10.1016/j.scitotenv.2019.04.355

Constantinidou K., Hadjinicolaou P., Zittis G., and Lelieveld J. (2016). Effects of climate change on the yield of winter wheat in the eastern Mediterranean and Middle East. *Climate Research*, *69*(2), 129–141. doi: 10.3354/cr01395

Cooper J. A. G., and Pilkey O. H. (2004). Sea-level rise and shoreline retreat: time to abandon the Bruun Rule. *Global and Planetary Change*, *43*(3–4), 157–171. doi: 10.1016/j.gloplacha.2004.07.001

Corcoll N., Acuña V., Barceló D., Casellas M., Guasch H., Huerta B., Petrovic M., Ponsatí L., Rodríguez-Mozaz S., and Sabater S. (2014). Pollution-induced community tolerance to non-steroidal anti-inflammatory drugs (NSAIDs) in fluvial biofilm communities affected by WWTP effluents. *Chemosphere*, *112*, 185–193. doi: 10.1016/j.chemosphere.2014.03.128

Cortès M., Turco M., Ward P., Sánchez-Espigares J. A., Alfieri L., and Llasat M. C. (2019). Changes in flood damage with global warming in the east coast of Spain. *Nat. Hazards Earth Syst. Sci.*, *19*, 2855–2877. https://doi.org/10.5194/nhess-19-2855-2019

Costello M. J., Vale M. M. KiesslingW., Maharaj S., Price J., and Talukdar G. H. (2022). Cross-Chapter Paper 1: Biodiversity Hotspots. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 2123–2162). Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2123–2161. doi: 10.1017/9781009325844.018

Couasnon A., Eilander D., Muis S., Veldkamp T. I. E., Haigh I. D., Wahl T., Winsemius H. C., and Ward P. J. (2020). Measuring compound flood potential from river discharge and storm surge extremes at the global scale. *Natural Hazards and Earth System Sciences*, *20*(2), 489–504. doi: 10.5194/nhess-20-489-2020

Crain C. M., Kroeker K., and Halpern B. S. (2008). Interactive and cumulative effects of multiple human stressors in marine systems. *Ecology Letters*, *11*(12), 1304–1315. doi: 10.1111/j.1461-0248.2008.01253.x

Cramer W., Guiot J., Fader M., Garrabou J., Gattuso J.-P., Iglesias A., Lange M. A., Lionello P., Llasat M. C., Paz S., Peñuelas J., Snoussi M., Toreti A., Tsimplis M. N., and Xoplaki E. (2018). Climate change and interconnected risks to sustainable development in the Mediterranean. *Nature Climate Change*, *8*(11), 972–980. doi: 10.1038/s41558-018-0299-2

Crozier L. G., Hendry A. P., Lawson P. W., Quinn T. P., Mantua N. J., Battin J., Shaw R. G., and Huey R. B. (2008). Potential responses to climate change in organisms with complex life histories: evolution and plasticity in Pacific salmon. *Evolutionary Applications*, *1*(2), 252–270. doi: 10.1111/J.1752-4571.2008.00033.x

Cubillo A. M., Ferreira J. G., Lencart-Silva J., Taylor N. G. H., Kennerley A., Guilder J., Kay S., and Kamermans P. (2021). Direct effects of climate change on productivity of European aquaculture. *Aquaculture International*, *29*(4), 1561–1590. doi: 10.1007/s10499-021-00694-6

Custodio E. (2017). *Salinización de las aguas subterráneas en los acuíferos costeros mediterráneos e insulares españoles*. Iniciativa Digital Politècnica, Oficina de Publicacions Acadèmiques Digitals de la UPC. doi: 10.5821/ebook-9788498806878

Daccache A., Ciurana J. S., Rodriguez Diaz J. A., and Knox J. W. (2014). Water and energy footprint of irrigated agriculture in the Mediterranean region. *Environmental Research Letters*, *9*(12), 124014. doi: 10.1088/1748-9326/9/12/124014

Danopoulos E., Twiddy M., West R., and Rotchell J. M. (2022). A rapid review and meta-regression analyses of the toxicological impacts of microplastic exposure in human cells. *Journal of Hazardous Materials*, *427*, 127861. doi: 10.1016/j.jhazmat.2021.127861

Danovaro R., Fonda Umani S., and Pusceddu A. (2009). Climate Change and the Potential Spreading of Marine Mucilage and Microbial Pathogens in the Mediterranean Sea. *PLoS ONE*, *4*(9), e7006. doi: 10.1371/journal.pone.0007006

Daoudy M., Sowers J., and Weinthal E. (2022). What is climate security? Framing risks around water, food, and migration in the Middle East and North Africa. *WIREs Water*, *9*(3). doi: 10.1002/wat2.1582

Dasgupta S., Laplante B., Meisner C., Wheeler D., and Yan J. (2009). The impact of sea level rise on developing countries: A comparative analysis. *Climatic Change*, *93*(3–4), 379–388. doi: 10.1007/S10584-008-9499-5

Daskalaki P., and Voudouris K. (2008). Groundwater quality of porous aquifers in Greece: a synoptic review. *Environmental Geology*, *54*(3), 505–513. doi: 10.1007/s00254-007-0843-2

Daughton C. G., and Ternes T. A. (1999). Pharmaceuticals and personal care products in the environment: agents of subtle change? *Environmental Health Perspectives*, *107*(suppl 6), 907–938. doi: 10.1289/ehp.99107s6907

de Almeida B. A., and Mostafavi A. (2016). Resilience of Infrastructure Systems to Sea-Level Rise in Coastal Areas: Impacts, Adaptation Measures, and Implementation Challenges. *Sustainability, 8*(11), 1115. doi: 10.3390/SU8111115

De Donno A., Idolo A., Bagordo F., Grassi T., Leomanni A., Serio F., Guido M., Canitano M., Zampardi S., Boero F., and Piraino S. (2014). Impact of Stinging Jellyfish Proliferations along South Italian Coasts: Human Health Hazards, Treatment and Social Costs. *International Journal of Environmental Research and Public Health 2014, Vol. 11, Pages 2488-2503*, *11*(3), 2488–2503. doi: 10.3390/ijerph110302488

De Vivo C., Ellena M., Capozzi V., Budillon G., and Mercogliano P. (2022). Risk assessment framework for Mediterranean airports: a focus on extreme temperatures and precipitations and sea level rise. *Natural Hazards*, *111*(1), 547–566. doi: 10.1007/s11069-021-05066-0

Defeo O., McLachlan A., Schoeman D. S., Schlacher T. A., Dugan J., Jones A., Lastra M., and Scapini F. (2009). Threats to sandy beach ecosystems: A review. *Estuarine, Coastal and Shelf Science*, *81*(1), 1–12. doi: 10.1016/j.ecss.2008.09.022

Dehm J., Singh S., Ferreira M., Piovano S., and Fick J. (2021). Screening of pharmaceuticals in coastal waters of the southern coast of Viti Levu in Fiji, South Pacific. *Chemosphere*, *276*, 130161. doi: 10.1016/j.chemosphere.2021.130161

del Moral A., Llasat M. del C., and Rigo T. (2020). Connecting flash flood events with radar-derived convective storm characteristics on the northwestern Mediterranean coast: knowing the present for better future scenarios adaptation. *Atmospheric Research*, *238*, 104863. doi: 10.1016/j.atmosres.2020.104863

Del Negro P., Crevatin E., Larato C., Ferrari C., Totti C., Pompei M., Giani M., Berto D., and Fonda Umani S. (2005). Mucilage microcosms. *Science of The Total Environment*, *353*(1–3), 258–269. doi: 10.1016/j.scitotenv.2005.09.018

Del Pozo A., Brunel-Saldias N., Engler A., Ortega-Farias S., Acevedo-Opazo C., Lobos G. A., Jara-Rojas R., and Molina-Montenegro M. A. (2019). Climate Change Impacts and Adaptation Strategies of Agriculture in Mediterranean-Climate Regions (MCRs). *Sustainability*, *11*(10), 2769. doi: 10.3390/su11102769

Delannoy C. M. J., Houghton J. D. R., Fleming N. E. C., and Ferguson H. W. (2011). Mauve Stingers (Pelagia noctiluca) as carriers of the bacterial fish pathogen Tenacibaculum maritimum. *Aquaculture*, *311*(1–4), 255–257. doi: 10.1016/j.aquaculture.2010.11.033

Demirel H., Kompil M., and Nemry F. (2015). A framework to analyze the vulnerability of European road networks due to Sea-Level Rise (SLR) and sea storm surges. *Transportation Research Part A: Policy and Practice*, *81*, 62–76. doi: 10.1016/j.tra.2015.05.002

Demirel N., Ulman A., Yıldız T., and Ertör-Akyazi P. (2021). A moving target: Achieving good environmental status and social justice in the case of an alien species, Rapa whelk in the Black Sea. *Marine Policy*, *132*, 104687. doi: 10.1016/j.marpol.2021.104687

Demirel N., Zengin M., and Ulman A. (2020). First Large-Scale Eastern Mediterranean and Black Sea Stock Assessment Reveals a Dramatic Decline. *Frontiers in Marine Science*, *7*, 482732. doi: 10.3389/fmars.2020.00103

Depew D. C., Basu N., Burgess N. M., Campbell L. M., Devlin E. W., Drevnick P. E., Hammerschmidt C. R., Murphy C. A., Sandheinrich M. B., and Wiener J. G. (2012). Toxicity of dietary methylmercury to fish: Derivation of ecologically meaningful threshold concentrations. *Environmental Toxicology and Chemistry*, *31*(7), 1536–1547. doi: 10.1002/etc.1859

Dewidar Kh., and Frihy O. (2007). Pre- and post-beach response to engineering hard structures using Landsat time-series at the northwestern part of the Nile delta, Egypt. *Journal of Coastal Conservation*, *11*(2), 133–142. doi: 10.1007/s11852-008-0013-z

Di Paola G., Rizzo A., Benassai G., Corrado G., Matano F., and Aucelli P. P. C. (2021). Sea-level rise impact and future scenarios of inundation risk along the coastal plains in Campania (Italy). *Environmental Earth Sciences*, *80*(17), 608. doi: 10.1007/s12665-021-09884-0

Diakakis M., Papagiannaki K., and Fouskaris M. (2023). The Occurrence of Catastrophic Multiple-Fatality Flash Floods in the Eastern Mediterranean Region. *Water*, *15*(1), 119. doi: 10.3390/w15010119

Díaz S., Settele J., Brondízio E. S., Ngo H. T., Agard J., Arneth A., Balvanera P., Brauman K. A., Butchart S. H. M., Chan K. M. A., Garibaldi L. A., Ichii K., Liu J., Subramanian S. M., Midgley G. F., Miloslavich P., Molnár Z., Obura D., Pfaff A., … Zayas C. N. (2019). Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science*, *366*(6471), eaax3100. doi: 10.1126/science.aax3100

Diaz-Almela E., Marbà N., and Duarte C. M. (2007). Consequences of Mediterranean warming events in seagrass (Posidonia oceanica) flowering records. *Global Change Biology*, *13*(1), 224–235. doi: 10.1111/J.1365-2486.2006.01260.x

Dimitriadis C., Fournari-Konstantinidou I., Sourbès L., Koutsoubas D., and Katsanevakis S. (2021). Long Term Interactions of Native and Invasive Species in a Marine Protected Area Suggest Complex Cascading Effects Challenging Conservation Outcomes. *Diversity*, *13*(2), 71. doi: 10.3390/d13020071

Dixit P. N., Telleria R., Al Khatib A. N., and Allouzi S. F. (2018). Decadal analysis of impact of future climate on wheat production in dry Mediterranean environment: A case of Jordan. *Science of The Total Environment*, *610–611*, 219–233. doi: 10.1016/j.scitotenv.2017.07.270

Doğan E., and Burak S. (2007). Ship-Originated Pollution in the Istanbul Strait (Bosphorus) and Marmara Sea. *Journal of Coastal Research*, *23*(2), 388–394. doi: 10.2112/04-0283.1

Dogru T., Bulut U., and Sirakaya-Turk E. (2016). Theory of Vulnerability and Remarkable Resilience of Tourism Demand to Climate Change: Evidence from the Mediterranean Basin. *Tourism Analysis*, *21*(6), 645–660. doi: 10.3727/108354216x14713487283246

Dono G., Cortignani R., Dell'Unto D., Deligios P., Doro L., Lacetera N., Mula L., Pasqui M., Quaresima S., Vitali A., and Roggero P. P. (2016). Winners and losers from climate change in agriculture: Insights from a case study in the Mediterranean basin. *Agricultural Systems*, *147*, 65–75. doi: 10.1016/j.agsy.2016.05.013

Drobinski P., Azzopardi B., Ben Janet Allal H., Bouchet V., Civel E., Creti A., Duic N., Fylaktos N., Mutale J., Pariente-David S., Ravetz J., Taliotis C., and Vautard R. (2020). Energy transition in the Mediterranean. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report*. Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, pp. 265-322. doi: 10.5281/zenodo.7101088

Dunn F. E., Darby S. E., Nicholls R. J., Cohen S., Zarfl C., and Fekete B. M. (2019). Projections of declining fluvial sediment delivery to major deltas worldwide in response to climate change and anthropogenic stress. *Environmental Research Letters*, *14*(8), 084034. doi: 10.1088/1748-9326/ab304e

EC, Cassar M., Sabbioni C., and Brimblecombe P. (2010). *The atlas of climate change impact on European cultural heritage – Scientific analysis and management strategies* (M. Cassar, C. Sabbioni, & P. Brimblecombe, Eds.). Anthem Press. doi: 10.2777/11959

EEA (2009). *Salt water intrusions into groundwater in Europe (1999)*. https://www.eea.europa.eu/en/analysis/maps-and-charts/salt-water-intrusions-into-groundwater-in-europe-1999

El-Amier Y. A., Bessa A. Z. E., Elsayed A., El-Esawi M. A., AL-Harbi M. S., Samra B. N., and Kotb W. K. (2021). Assessment of the Heavy Metals Pollution and Ecological Risk in Sediments of Mediterranean Sea Drain Estuaries in Egypt and Phytoremediation Potential of Two Emergent Plants. *Sustainability*, *13*(21), 12244. doi: 10.3390/su132112244

El-Magd I. A., Zakzouk M., Ali E. M., and Abdulaziz A. M. (2021). An Open Source Approach for Near-Real Time Mapping of Oil Spills along the Mediterranean Coast of Egypt. *Remote Sensing 2021, Vol. 13, Page 2733*, *13*(14), 2733. doi: 10.3390/RS13142733

El-Masry E. A., El-Sayed M. Kh., Awad M. A., El-Sammak A. A., and Sabarouti M. A. El. (2022). Vulnerability of tourism to climate change on the Mediterranean coastal area of El Hammam–EL Alamein, Egypt. *Environment, Development and Sustainability*, *24*(1), 1145–1165. doi: 10.1007/s10668-021-01488-9

El-Nahry A. H., and Doluschitz R. (2010). Climate change and its impacts on the coastal zone of the Nile Delta, Egypt. *Environmental Earth Sciences*, *59*(7), 1497–1506. doi: 10.1007/s12665-009-0135-0

El-Raey M. (2010). Impacts and Implications of Climate Change for the Coastal Zones of Egypt from Coastal Zones and Climate Change on JSTOR. *Coastal Zones and Climate Change*, 31–50. https://www.jstor.org/stable/resrep10902.9

El-Raey M., Frihy O., Nasr S. M., and Dewidar Kh. (1999). Vulnerability Assessment of Sea Level Rise Over Port Said Governorate, Egypt. *Environmental Monitoring and Assessment*, *56*(2), 113–128. doi: 10.1023/A:1005946819600

Enríquez A. R., and Bujosa Bestard A. (2020). Measuring the economic impact of climate-induced environmental changes on sun-and-beach tourism. *Climatic Change*, *160*(2), 203–217. doi: 10.1007/s10584-020-02682-w

Esplugas S., Bila D. M., Krause L. G. T., and Dezotti M. (2007). Ozonation and advanced oxidation technologies to remove endocrine disrupting chemicals (EDCs) and pharmaceuticals and personal care products (PPCPs) in water effluents. *Journal of Hazardous Materials*, *149*(3), 631–642. doi: 10.1016/j.jhazmat.2007.07.073

Estaque T., Richaume J., Bianchimani O., Schull Q., Mérigot B., Bensoussan N., Bonhomme P., Vouriot P., Sartoretto S., Monfort T., Basthard-Bogain S., Fargetton M., Gatti G., Barth L., Cheminée A., and Garrabou J. (2023). Marine heatwaves on the rise: One of the strongest ever observed mass mortality event in temperate gorgonians. *Global Change Biology*, *29*(22), 6159–6162. doi: 10.1111/gcb.16931

Estrela-Segrelles C., Gómez-Martinez G., and Pérez-Martín M. Á. (2021). Risk assessment of climate change impacts on Mediterranean coastal wetlands. Application in Júcar River Basin District (Spain). *Science of The Total Environment*, *790*, 148032. doi: 10.1016/j.scitotenv.2021.148032

Faccini F., Luino F., Paliaga G., Roccati A., and Turconi L. (2021). Flash Flood Events along the West Mediterranean Coasts: Inundations of Urbanized Areas Conditioned by Anthropic Impacts. *Land*, *10*(6), 620. doi: 10.3390/land10060620

Fader M., Giupponi C., Burak S., Dakhlaoui H., Koutroulis A., Lange M. A., Llasat M. C., Pulido-Velazquez D., and Sanz-Cobeña A. (2020). Water. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report* (pp. 181–236). Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France. doi: 10.5281/zenodo.7101074

Fader M., Shi S., Von Bloh W., Bondeau A., and Cramer W. (2016). Mediterranean irrigation under climate change: more efficient irrigation needed to compensate for increases in irrigation water requirements. *Hydrology and Earth System Sciences*, *20*(2), 953–973. doi: 10.5194/hess-20-953-2016

FAO (2015). Climate change and food security: risks and responses. In *United Nations Human Settlements Programme (UN-Habitat): Addis Ababa, Ethiopia. (2021)*. FAO, Rome, Italy. https://openknowledge.fao.org/handle/20.500.14283/i5188e

FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. In *The State of World Fisheries and Aquaculture 2020. In brief*. FAO. doi: 10.4060/CA9231en

FAO (2022). The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. In *The State of World Fisheries and Aquaculture 2022*. Rome, FAO. doi: 10.4060/cc0461en

Fawaz M. M., and Soliman S. A. (2016). The Potential Scenarios of the Impacts of Climate Change on Egyptian Resources and Agricultural Plant Production. *Open Journal of Applied Sciences*, *06*(04), 270–286. doi: 10.4236/ojapps.2016.64027

Ferrarin C., Valentini A., Vodopivec M., Klaric D., Massaro G., Bajo M., De Pascalis F., Fadini A., Ghezzo M., Menegon S., Bressan L., Unguendoli S., Fettich A., Jerman J., Ličer M., Fustar L., Papa A., and Carraro E. (2020). Integrated sea storm management strategy: the 29 October 2018 event in the Adriatic Sea. *Natural Hazards and Earth System Sciences*, *20*(1), 73–93. doi: 10.5194/nhess-20-73-2020

Ferrarini A., Celada C., and Gustin M. (2021). Preserving the Mediterranean bird flyways: Assessment and prioritization of 38 main wetlands under human and climate threats in Sardinia and Sicily (Italy). *Science of The Total Environment*, *751*, 141556. doi: 10.1016/j.scitotenv.2020.141556

Ferreira C. S. S., Seifollahi-Aghmiuni S., Destouni G., Ghajarnia N., and Kalantari Z. (2022). Soil degradation in the European Mediterranean region: Processes, status and consequences. *Science of The Total Environment*, *805*, 150106. doi: 10.1016/j.scitotenv.2021.150106

Ferrise R., Moriondo M., and Bindi M. (2011). Probabilistic assessments of climate change impacts on durum wheat in the Mediterranean region. *Natural Hazards and Earth System Sciences*, *11*(5), 1293–1302. doi: 10.5194/nhess-11-1293-2011

Ferrise R., Trombi G., Moriondo M., and Bindi M. (2016). Climate Change and Grapevines: A Simulation Study for the Mediterranean Basin. *Journal of Wine Economics*, *11*(1), 88–104. doi: 10.1017/jwe.2014.30

Finenko G. A., Romanova Z. A., Abolmasova G. I., Anninsky B. E., Svetlichny L. S., Hubareva E. S., Bat L., and Kideys A. E. (2003). Population dynamics, ingestion, growth and reproduction rates of the invader Beroe ovata and its impact on plankton community in Sevastopol Bay, the Black Sea. *Journal of Plankton Research*, *25*(5), 539–549. doi: 10.1093/plankt/25.5.539

FitzGerald D. M., Fenster M. S., Argow B. A., and Buynevich I. V. (2008). Coastal Impacts Due to Sea-Level Rise. *Annual Review of Earth and Planetary Sciences*, *36*(1), 601–647. doi: 10.1146/annurev.earth.35.031306.140139

Flouros F. (2022). The Energy Security in the Mediterranean Region. In: *Energy Security in the Eastern Mediterranean Region* Palgrave Macmillan, Cham. Springer International Publishing. doi: 10.1007/978-3-031-09603-7_4

Fonseca V. F., França S., Duarte B., Caçador I., Cabral H. N., Mieiro C. L., Coelho J. P., Pereira E., and Reis-Santos P. (2019). Spatial Variation in Mercury Bioaccumulation and Magnification in a Temperate Estuarine Food Web. *Frontiers in Marine Science*, *6*, 117. doi: 10.3389/fmars.2019.00117

Fossi M. C., Romeo T., Baini M., Panti C., Marsili L., Campan T., Canese S., Galgani F., Druon J. N., Airoldi S., Taddei S., Fattorini M., Brandini C., and Lapucci C. (2017). Plastic debris occurrence, convergence areas and fin whales feeding ground in the Mediterranean marine protected area Pelagos Sanctuary: A modeling approach. *Frontiers in Marine Science*, *4*(MAY), 254370. doi: 10.3389/fmars.2017.00167

Fraga H., Moriondo M., Leolini L., and Santos J. A. (2020a). Mediterranean Olive Orchards under Climate Change: A Review of Future Impacts and Adaptation Strategies. *Agronomy*, *11*(1), 56. doi: 10.3390/agronomy11010056

Fraga H., Pinto J. G., Viola F., and Santos J. A. (2020b). Climate change projections for olive yields in the Mediterranean Basin. *International Journal of Climatology*, *40*(2), 769–781. doi: 10.1002/joc.6237

Fraixedas S., Galewski T., Ribeiro-Lopes S., Loh J., Blondel J., Fontès H., Grillas P., Lambret P., Nicolas D., Olivier A., and Geijzendorffer I. R. (2019). Estimating biodiversity changes in the Camargue wetlands: An expert knowledge approach. *PLOS ONE*, *14*(10), e0224235. doi: 10.1371/journal.pone.0224235

Funes I., Savé R., De Herralde F., Biel C., Pla E., Pascual D., Zabalza J., Cantos G., Borràs G., Vayreda J., and Aranda X. (2021). Modeling impacts of climate change on the water needs and growing cycle of crops in three Mediterranean basins. *Agricultural Water Management*, *249*, 106797. doi: 10.1016/j.agwat.2021.106797

Galeotti M. (2020). The Economic impacts of climate change in the Mediterranean. *IEMed. Mediterranean Yearbook 2020*, 46–54. https://www.iemed.org/publication/the-economic-impacts-of-climate-change-in-the-mediterranean/

Galil B., Marchini A., Occhipinti-Ambrogi A., and Ojaveer H. (2017). The enlargement of the Suez Canal—Erythraean introductions and management challenges. *Management of Biological Invasions*, *8*(2), 141–152. doi: 10.3391/mbi.2017.8.2.02

García-Garizábal I., Causapé J., Abrahao R., and Merchan D. (2014). Impact of Climate Change on Mediterranean Irrigation Demand: Historical Dynamics of Climate and Future Projections. *Water Resources Management*, *28*(5), 1449–1462. doi: 10.1007/s11269-014-0565-7

Garola A., López-Dóriga U., and Jiménez J. A. (2022). The economic impact of sea level rise-induced decrease in the carrying capacity of Catalan beaches (NW Mediterranean, Spain). *Ocean & Coastal Management*, *218*, 106034. doi: 10.1016/j.ocecoaman.2022.106034

Garrabou J., Gómez-Gras D., Ledoux J.-B., Linares C., Bensoussan N., López-Sendino P., Bazairi H., Espinosa F., Ramdani M., Grimes S., Benabdi M., Souissi J. Ben, Soufi E., Khamassi F., Ghanem R., Ocaña O., Ramos-Esplà A., Izquierdo A., Anton I., … Harmelin J. G. (2019). Collaborative Database to Track Mass Mortality Events in the Mediterranean Sea. *Frontiers in Marine Science*, *6*, 707. doi: 10.3389/fmars.2019.00707

Garrabou J., Gómez-Gras D., Medrano A., Cerrano C., Ponti M., Schlegel R., Bensoussan N., Turicchia E., Sini M., Gerovasileiou V., Teixido N., Mirasole A., Tamburello L., Cebrian E., Rilov G., Ledoux J., Souissi J. Ben, Khamassi F., Ghanem R., … Harmelin J. (2022). Marine heatwaves drive recurrent mass mortalities in the Mediterranean Sea. *Global Change Biology*, *28*(19), 5708–5725. doi: 10.1111/gcb.16301

Gauer R., and Meyers B. K. (2019). Heat-Related Illnesses. *American Family Physician*, *99*(8), 482–489. https://www.aafp.org/pubs/afp/issues/2019/0415/p482.html

Gaume E., Borga M., Llassat M. C., Maouche S., Lang M., and Diakakis M. (2016). *Mediterranean extreme floods and flash floods*. 133. https://hal.science/hal-01465740

Gervais M., Balouin Y., and Belon R. (2012). Morphological response and coastal dynamics associated with major storm events along the Gulf of Lions Coastline, France. *Geomorphology*, *143–144*, 69–80. doi: 10.1016/j.geomorph.2011.07.035

Geyer R., Jambeck J. R., and Law K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances*, *3*(7), e1700782. doi: 10.1126/sciadv.1700782

Ghermandi A., Galil B., Gowdy J., and Nunes P. A. L. D. (2015). Jellyfish outbreak impacts on recreation in the Mediterranean Sea: welfare estimates from a socioeconomic pilot survey in Israel. *Ecosystem Services*, *11*, 140–147. doi: 10.1016/j.ecoser.2014.12.004

Giorgi F. (2006). Climate change hot-spots. *Geophysical Research Letters*, *33*(8), 8707. doi: 10.1029/2006gl025734

Gohar A., and Kondolf G. M. (2017). Flash flooding as a threat to settlements even in remote areas. *Environment and Urbanization*, *29*(2), 503–514. doi: 10.1177/0956247816672158

Gökçekuş H., Kassem Y., Quoigoah M. P., and Aruni P. N. (2021). Climate change, water resources, and wastewater reuse in Cyprus. *Future Technology*, *1*, 1–12. https://fupubco.com/futech/article/view/46

Gomez-Gomez J.-D., Pulido-Velazquez D., Collados-Lara A.-J., and Fernandez-Chacon F. (2022). The impact of climate change scenarios on droughts and their propagation in an arid Mediterranean basin. A useful approach for planning adaptation strategies. *Science of The Total Environment*, *820*, 153128. doi: 10.1016/j.scitotenv.2022.153128

Gómez-Losada Á., and Pires J. C. M. (2020). Estimation of Particulate Matter Contributions from Desert Outbreaks in Mediterranean Countries (2015–2018) Using the Time Series Clustering Method. *Atmosphere 2021, Vol. 12, Page 5*, *12*(1), 5. doi: 10.3390/atmos12010005

González-Gaya B., García-Bueno N., Buelow E., Marin A., and Rico A. (2022). Effects of aquaculture waste feeds and antibiotics on marine benthic ecosystems in the Mediterranean Sea. *Science of The Total Environment*, *806*, 151190. doi: 10.1016/j.scitotenv.2021.151190

Grasso M., and Feola G. (2012). Mediterranean agriculture under climate change: adaptive capacity, adaptation, and ethics. *Regional Environmental Change*, *12*(3), 607–618. doi: 10.1007/s10113-011-0274-1

Green A. J., Alcorlo P., Peeters E. T., Morris E. P., Espinar J. L., Bravo-Utrera M. A., Bustamante J., Díaz-Delgado R., Koelmans A. A., Mateo R., Mooij W. M., Rodríguez-Rodríguez M., Van Nes E. H., and Scheffer M. (2017). Creating a safe operating space for wetlands in a changing climate. *Frontiers in Ecology and the Environment*, *15*(2), 99–107. doi: 10.1002/fee.1459

Grigorakis K., and Rigos G. (2011). Aquaculture effects on environmental and public welfare – The case of Mediterranean mariculture. *Chemosphere*, *85*(6), 899–919. doi: 10.1016/j.chemosphere.2011.07.015

Gueroun S. K. M., Molinero J. C., Piraino S., and Yahia M. N. D. (2020). Population dynamics and predatory impact of the alien jellyfish Aurelia solida (Cnidaria, Scyphozoa) in the Bizerte Lagoon (southwestern Mediterranean Sea). *Mediterranean Marine Science*, *21*(1), 22-35. doi: 10.12681/mms.17358

Guiot J., and Cramer W. (2016). Climate change: The 2015 Paris Agreement thresholds and Mediterranean basin ecosystems. *Science*, *354*(6311), 465–468. doi: 10.1126/science.aah5015

Gümrükçüoğlu Yiğit M. (2022). Water Related Sectors and Risks in Adaptation to Climate Change. In H. Gökçekuş & Y. Kassem (Eds.), *Climate Change, Natural Resources and Sustainable Environmental Management* Environmental Earth Sciences. Springer, Cham. doi : 10.1007/978-3-031-04375-8_3

Gunderson A. R., Armstrong E. J., and Stillman J. H. (2016). Multiple Stressors in a Changing World: The Need for an Improved Perspective on Physiological Responses to the Dynamic Marine Environment. *Annual Review of Marine Science*, *8*(1), 357–378. doi: 10.1146/annurev-marine-122414-033953

Habib R. R., Zein K. El, and Ghanawi J. (2010). Climate change and health research in the Eastern Mediterranean Region. *EcoHealth*, *7*(2), 156–175. doi: 10.1007/S10393-010-0330-1

Hadri A., Saidi M. E. M., El Khalki E. M., Aachrine B., Saouabe T., and Elmaki A. A. (2022). Integrated water management under climate change through the application of the WEAP model in a Mediterranean arid region. *Journal of Water and Climate Change*, *13*(6), 2414–2442. doi: 10.2166/wcc.2022.039

Hall C. M., and Ram Y. (2018). Case Study Israel: Coastal tourism, coastal planning and climate change in Israel. In A. Jones & M. Phillips (Eds.), *Global climate change and coastal tourism: recognizing problems, managing solutions and future expectations* (1st ed., pp. 263–272). CABI. doi: 10.1079/9781780648439.0263

Halpern B. S., Walbridge S., Selkoe K. A., Kappel C. V, Micheli F., D'Agrosa C., Bruno J. F., Casey K. S., Ebert C., Fox H. E., Fujita R., Heinemann D., Lenihan H. S., Madin E. M. P., Perry M. T., Selig E. R., Spalding M., Steneck R., and Watson R. (2008). A Global Map of Human Impact on Marine Ecosystems. *Science*, *319*(5865), 948–952. doi: 10.1126/science.1149345

Harley C. D. G., Randall Hughes A., Hultgren K. M., Miner B. G., Sorte C. J. B., Thornber C. S., Rodriguez L. F., Tomanek L., and Williams S. L. (2006). The impacts of climate change in coastal marine systems. *Ecology Letters*, *9*(2), 228–241. doi: 10.1111/j.1461-0248.2005.00871.x

Hassoun A. E. R., Bantelman A., Canu D., Comeau S., Galdies C., Gattuso J. P., Giani M., Grelaud M., Hendriks I. E., Ibello V., Idrissi M., Krasakopoulou E., Shaltout N., Solidoro C., Swarzenski P. W., and Ziveri P. (2022). Ocean acidification research in the Mediterranean Sea: Status, trends and next steps. *Frontiers in Marine Science*, *9*, 892670. doi: 10.3389/fmars.2022.892670

Hauer M. E., Fussell E., Mueller V., Burkett M., Call M., Abel K., McLeman R., and Wrathall D. (2020). Sea-level rise and human migration. *Nature Reviews Earth & Environment*, *1*(1), 28–39. doi: 10.1038/s43017-019-0002-9

Heaviside C., Tsangari H., Paschalidou A., Vardoulakis S., Kassomenos P., Georgiou K. E., and Yamasaki E. N. (2016). Heat-related mortality in Cyprus for current and future climate scenarios. *Science of the Total Environment*, *569–570*, 627–633. doi: 10.1016/j.scitotenv.2016.06.138

Hereher M. E. (2015). Coastal vulnerability assessment for Egypt's Mediterranean coast. *Geomatics, Natural Hazards and Risk*, *6*(4), 342–355. doi: 10.1080/19475705.2013.845115

Hidalgo M., Mihneva V., Vasconcellos M., and Bernal M. (2018). Climate change impacts, vulnerabilities and adaptations: Mediterranean Sea and the Black Sea marine fisheries. In M. Barange, T. Bahri, M. C. M. Beveridge, K. L. Cochrane, S. Funge-Smith, & F. Poulain (Eds.), *Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options.* (pp. 139–157). FAO Fisheries and Aquaculture Technical Paper No. 627. Rome, FAO. https://openknowledge.fao.org/handle/20.500.14283/i9705en/

Higuera-Llantén S., Vásquez-Ponce F., Barrientos-Espinoza B., Mardones F. O., Marshall S. H., and Olivares-Pacheco J. (2018). Extended antibiotic treatment in salmon farms select multiresistant gut bacteria with a high prevalence of antibiotic resistance genes. *PLOS ONE*, *13*(9), e0203641. doi: 10.1371/journal.pone.0203641

Hinkel J., Jaeger C., Nicholls R. J., Lowe J., Renn O., and Peijun S. (2015). Sea-level rise scenarios and coastal risk management. *Nature Climate Change*, *5*(3), 188–190. doi: 10.1038/nclimate2505

Hinkel J., Lincke D., Vafeidis A. T., Perrette M., Nicholls R. J., Tol R. S. J., Marzeion B., Fettweis X., Ionescu C., and Levermann A. (2014). Coastal flood damage and adaptation costs under 21st century sea-level rise. *Proceedings of the National Academy of Sciences*, *111*(9), 3292–3297. doi: 10.1073/pnas.1222469111

Hodžić M. (1979). Occurrences of exceptional sea-level oscillations in the Vela Luka Bay. *Priroda (in Croatian)*, *68*, 52–53.

Hossain A., Sabagh A. EL, Barutcular C., Bhatt R., Çiğ F., Seydoşoğlu S., Turan N., Konuskan O., Aamir Iqbal M., Abdelhamid M., Tojo Soler C. M., Laing A., and Saneoka H. (2020). Sustainable crop production to ensuring food security under climate change: A Mediterranean perspective. *AJCS*, *14*(03), 1835–2707. doi: 10.21475/ajcs.20.14.03.p1976

Houngnandan F., Kefi S., Bockel T., and Deter J. (2022). The joint influence of environmental and anthropogenic factors on the invasion of two alien caulerpae in northwestern Mediterranean. *Biological Invasions*, *24*(2), 449–462. doi: 10.1007/s10530-021-02654-w

Howarth R. W. (2008). Coastal nitrogen pollution: A review of sources and trends globally and regionally. *Harmful Algae*, *8*(1), 14–20. doi: 10.1016/j.hal.2008.08.015

Ibáñez C., and Caiola N. (2021). Sea-level rise, marine storms and the resilience of Mediterranean coastal wetlands: lessons learned from the Ebro Delta. *Marine and Freshwater Research*, *73*(10), 1246–1254. doi: 10.1071/mf21140

Iglesias A., and Garrote L. (2018). Local and Collective Actions for Adaptation to Use Less Water for Agriculture in the Mediterranean Region. In *Water Scarcity and Sustainable Agriculture in Semiarid Environment* (pp. 73–84). Elsevier. doi: 10.1016/b978-0-12-813164-0.00004-1

Iglesias A., Garrote L., Diz A., Schlickenrieder J., and Martin-Carrasco F. (2011). Re-thinking water policy priorities in the Mediterranean region in view of climate change. *Environmental Science & Policy*, *14*(7), 744–757. doi: 10.1016/j.envsci.2011.02.007

Impacts of climate change on fisheries and aquaculture. (2018). In M. Barange, T. Bahri, M. C. M. Beveridge, K. L. Cochrane, S. Funge-Smith, & F. Poulain (Eds.), *United Nations Human Settlements Programme (UN-Habitat): Addis Ababa, Ethiopia. (2021)*. FAO Fisheries and Aquaculture Technical Paper No. 627. Rome, FAO. 628 pp. https://openknowledge.fao.org/handle/20.500.14283/i9705en

Islam F., Wang J., Farooq M. A., Khan M. S. S., Xu L., Zhu J., Zhao M., Muños S., Li Q. X., and Zhou W. (2018). Potential impact of the herbicide 2,4-dichlorophenoxyacetic acid on human and ecosystems. *Environment International*, *111*, 332–351. doi: 10.1016/j.envint.2017.10.020

Izaguirre C., Losada I. J., Camus P., Vigh J. L., and Stenek V. (2021). Climate change risk to global port operations. *Nature Climate Change*, *11*(1), 14–20. doi: 10.1038/s41558-020-00937-z

Jambeck J. R., Geyer R., Wilcox C., Siegler T. R., Perryman M., Andrady A., Narayan R., and Law K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, *347*(6223), 768–771. doi: 10.1126/science.1260352

Jansà A., and Ramis C. (2021). The Balearic rissaga: from pioneering research to present-day knowledge. *Natural Hazards*, *106*(2), 1269–1297. doi: 10.1007/s11069-020-04221-3

Jiménez J. A., Sancho-García A., Bosom E., Valdemoro H. I., and Guillén J. (2012). Storm-induced damages along the Catalan coast (NW Mediterranean) during the period 1958–2008. *Geomorphology*, *143–144*, 24–33. doi: 10.1016/j.geomorph.2011.07.034

Jiménez J. A., Sanuy M., Ballesteros C., and Valdemoro H. I. (2018). The Tordera Delta, a hotspot to storm impacts in the coast northwards of Barcelona (NW Mediterranean). *Coastal Engineering*, *134*, 148–158. doi: 10.1016/j.coastaleng.2017.08.012

Jiménez J. A., and Valdemoro H. I. (2019). Shoreline Evolution and its Management Implications in Beaches Along the Catalan Coast. In J. A. Morales (Ed.), *The Spanish Coastal Systems: Dynamic Processes, Sediments and Management* (pp. 745–764). Springer International Publishing. doi: 10.1007/978-3-319-93169-2_32

Jiménez J. A., Valdemoro H. I., Bosom E., Sánchez-Arcilla A., and Nicholls R. J. (2017). Impacts of sea-level rise-induced erosion on the Catalan coast. *Regional Environmental Change*, *17*(2), 593–603. doi: 10.1007/s10113-016-1052-x

Jobbins G., and Henley G. (2015). *Food in an uncertain future: the impacts of climate change on food security and nutrition in the Middle East and North Africa*. Overseas Development Institute, London / World Food Programme, Rome. https://odi.org/en/publications/food-in-an-uncertain-future/

Joshi S. R., Vielle M., Babonneau F., Edwards N. R., and Holden P. B. (2016). Physical and Economic Consequences of Sea-Level Rise: A Coupled GIS and CGE Analysis Under Uncertainties. *Environmental and Resource Economics*, *65*(4), 813–839. doi: 10.1007/S10640-015-9927-8

Kapsomenakis J., Douvis C., Poupkou A., Zerefos S., Solomos S., Stavraka T., Melis N. S., Kyriakidis E., Kremlis G., and Zerefos C. (2023). Climate change threats to cultural and natural heritage UNESCO sites in the Mediterranean. *Environment, Development and Sustainability*, *25*(12), 14519–14544. doi: 10.1007/S10668-022-02677-w

Karagas M. R., Choi A. L., Oken E., Horvat M., Schoeny R., Kamai E., Cowell W., Grandjean P., and Korrick S. (2012). Evidence on the Human Health Effects of Low-Level Methylmercury Exposure. *Environmental Health Perspectives*, *120*(6), 799–806. doi: 10.1289/ehp.1104494

Karatayev A. Y., Burlakova L. E., and Padilla D. K. (2015). Zebra versus quagga mussels: a review of their spread, population dynamics, and ecosystem impacts. *Hydrobiologia*, *746*(1), 97–112. doi: 10.1007/S10750-014-1901-x

Karavani A., De Cáceres M., Martínez De Aragón J., Bonet J. A., and de-Miguel S. (2018). Effect of climatic and soil moisture conditions on mushroom productivity and related ecosystem services in Mediterranean pine stands facing climate change. *Agricultural and Forest Meteorology*, *248*, 432–440. doi: 10.1016/j.agrformet.2017.10.024

Kasmi S., Snoussi M., Khalfaoui O., Aitali R., and Flayou L. (2020). Increasing pressures, eroding beaches and climate change in Morocco. *Journal of African Earth Sciences*, *164*, 103796. doi: 10.1016/j.jafrearsci.2020.103796

Katircioglu S., Cizreliogullari M. N., and Katircioglu S. (2019). Estimating the role of climate changes on international tourist flows: evidence from Mediterranean Island States. *Environmental Science and Pollution Research*, *26*(14), 14393–14399. doi: 10.1007/s11356-019-04750-w

Katsanevakis S., Olenin S., Puntila-Dodd R., Rilov G., Stæhr P. A. U., Teixeira H., Tsirintanis K., Birchenough S. N. R., Jakobsen H. H., Knudsen S. W., Lanzén A., Mazaris A. D., Piraino S., and Tidbury H. J. (2023). Marine invasive alien species in Europe: 9 years after the IAS Regulation. *Frontiers in Marine Science*, *10*, 1271755. doi: 10.3389/fmars.2023.1271755

Katsanevakis S., Tempera F., and Teixeira H. (2016). Mapping the impact of alien species on marine ecosystems: the Mediterranean Sea case study. *Diversity and Distributions*, *22*(6), 694–707. doi: 10.1111/ddi.12429

Katsanevakis S., Wallentinus I., Zenetos A., Leppäkoski E., Çinar M. E., Oztürk B., Grabowski M., Golani D., and Cardoso A. C. (2014). Impacts of invasive alien marine species on ecosystem services and biodiversity: a pan-European review. *Aquatic Invasions*, *9*(4), 391–423. doi: 10.3391/ai.2014.9.4.01

Kavadia A., Omirou M., Fasoula D., and Ioannides I. M. (2020). The Importance of Microbial Inoculants in a Climate-Changing Agriculture in Eastern Mediterranean Region. *Atmosphere*, *11*(10), 1136. doi: 10.3390/atmos11101136

Khouakhi A., Niazi S., Raji O., and El Fahchouch A. N. (2015). Vulnerability assessment of seawater intrusion using hydro-geological indices in Moroccan Mediterranean aquifers. *International Journal of Hydrology Science and Technology*, *5*(2), 133–148. doi: 10.1504/ijhst.2015.070087

King O. C., Van De Merwe J. P., Campbell M. D., Smith R. A., Warne M. S. J., and Brown C. J. (2022). Interactions among multiple stressors vary with exposure duration and biological response. *Proceedings of the Royal Society B*, *289*(1974). doi: 10.1098/rspb.2022.0348

Kirezci E., Young I. R., Ranasinghe R., Muis S., Nicholls R. J., Lincke D., and Hinkel J. (2020). Projections of global-scale extreme sea levels and resulting episodic coastal flooding over the 21st Century. *Scientific Reports*, *10*(1), 11629. doi: 10.1038/s41598-020-67736-6

Kirwan M. L., and Guntenspergen G. R. (2010). Influence of tidal range on the stability of coastal marshland. *Journal of Geophysical Research: Earth Surface*, *115*(F2), 2009. doi: 10.1029/2009jf001400

Kleitou P., Moutopoulos D. K., Giovos I., Kletou D., Savva I., Cai L. L., Hall-Spencer J. M., Charitou A., Elia M., Katselis G., and Rees S. (2022). Conflicting interests and growing importance of non-indigenous species in commercial and recreational fisheries of the Mediterranean Sea. *Fisheries Management and Ecology*, *29*(2), 169–182. doi: 10.1111/fme.12531

Korkmaz N. E., Savun-Hekimoğlu B., Aksu A., Burak S., and Caglar N. B. (2022). Occurrence, sources and environmental risk assessment of pharmaceuticals in the Sea of Marmara, Turkey. *Science of The Total Environment*, *819*, 152996. doi: 10.1016/j.scitotenv.2022.152996

Kourgialas N. N., Koubouris G. C., Karatzas G. P., and Metzidakis I. (2016). Assessing water erosion in Mediterranean tree crops using GIS techniques and field measurements: the effect of climate change. *Natural Hazards*, *83*(1), 65–81. doi: 10.1007/S11069-016-2354-5

Koutroulis A. G., Grillakis M. G., Tsanis I. K., and Jacob D. (2018). Mapping the vulnerability of European summer tourism under 2°C global warming. *Climatic Change*, *151*(2), 157–171. doi: 10.1007/s10584-018-2298-8

Kuhfuss L., Rey-Valette H., Sourisseau E., Heurtefeux H., and Rufray X. (2016). Evaluating the impacts of sea level rise on coastal wetlands in Languedoc-Roussillon, France. *Environmental Science & Policy*, *59*, 26–34. doi: 10.1016/j.envsci.2016.02.002

Kumar L., Chhogyel N., Gopalakrishnan T., Hasan M. K., Jayasinghe S. L., Kariyawasam C. S., Kogo B. K., and Ratnayake S. (2022). Climate change and future of agri-food production. In *Future Foods* (pp. 49–79). Elsevier. doi: 10.1016/b978-0-323-91001-9.00009-8

Lacoue-Labarthe T., Nunes P. A. L. D., Ziveri P., Cinar M., Gazeau F., Hall-Spencer J. M., Hilmi N., Moschella P., Safa A., Sauzade D., and Turley C. (2016). Impacts of ocean acidification in a warming Mediterranean Sea: An overview. *Regional Studies in Marine Science*, *5*, 1–11. doi: 10.1016/j.rsma.2015.12.005

Landrigan P. J., Stegeman J. J., Fleming L. E., Allemand D., Anderson D. M., Backer L. C., Brucker-Davis F., Chevalier N., Corra L., Czerucka D., Bottein M.-Y. D., Demeneix B., Depledge M., Deheyn D. D., Dorman C. J., Fénichel P., Fisher S., Gaill F., Galgani F., ... Rampal P. (2020). Human Health and Ocean Pollution. *Annals of Global Health*, *86*(1), 151. doi: 10.5334/aogh.2831

Lange M. A. (2019). Impacts of Climate Change on the Eastern Mediterranean and the Middle East and North Africa Region and the Water–Energy Nexus. *Atmosphere*, *10*(8), 455. doi: 10.3390/atmos10080455

Lange M. A. (2022). Climate Change and the Water-Energy Nexus in the MENA Region. In V. Naddeo, K.-H. Choo, & M. Ksibi (Eds.), *Water-Energy-Nexus in the Ecological Transition* (pp. 93–98). Springer International Publishing. doi: 10.1007/978-3-031-00808-5_22

Lange R., and Marshall D. (2017). Ecologically relevant levels of multiple, common marine stressors suggest antagonistic effects. *Scientific Reports*, *7*(1), 6281. doi: 10.1038/s41598-017-06373-y

Le Cozannet G., Garcin M., Yates M., Idier D., and Meyssignac B. (2014). Approaches to evaluate the recent impacts of sea-level rise on shoreline changes. *Earth-Science Reviews*, *138*, 47–60. doi: 10.1016/j.earscirev.2014.08.005

Le Cozannet G., Oliveros C., Castelle B., Garcin M., Idier D., Pedreros R., and Rohmer J. (2016). Uncertainties in Sandy Shorelines Evolution under the Bruun Rule Assumption. *Frontiers in Marine Science*, *3*. doi: 10.3389/fmars.2016.00049

Leberger R., Geijzendorffer I. R., Gaget E., Gwelmami A., Galewski T., Pereira H. M., and Guerra C. A. (2020). Mediterranean wetland conservation in the context of climate and land cover change. *Regional Environmental Change*, *20*(2), 67. doi: 10.1007/s10113-020-01655-0

Leduc C., Pulido-Bosch A., and Remini B. (2017). Anthropization of groundwater resources in the Mediterranean region: processes and challenges. *Hydrogeology Journal 2017 25:6*, *25*(6), 1529–1547. doi: 10.1007/s10040-017-1572-6

Lefebvre G., Redmond L., Germain C., Palazzi E., Terzago S., Willm L., and Poulin B. (2019). Predicting the vulnerability of seasonally-flooded wetlands to climate change across the Mediterranean Basin. *Science of The Total Environment*, *692*, 546–555. doi: 10.1016/j.scitotenv.2019.07.263

Leissner J., Kilian R., Kotova L., Jacob D., Mikolajewicz U., Broström T., Ashley-Smith J., Schellen H. L., Martens M., Van Schijndel J., Antretter F., Winkler M., Bertolin C., Camuffo D., Simeunovic G., and Vyhlídal T. (2015). Climate for Culture: assessing the impact of climate change on the future indoor climate in historic buildings using simulations. *Heritage Science*, *3*(1), 38. doi: 10.1186/s40494-015-0067-9

Lentz E. E., Thieler E. R., Plant N. G., Stippa S. R., Horton R. M., and Gesch D. B. (2016). Evaluation of dynamic coastal response to sea-level rise modifies inundation likelihood. *Nature Climate Change*, *6*(7), 696–700. doi: 10.1038/nclimate2957

Leslie H. A., Van Velzen M. J. M., Brandsma S. H., Vethaak A. D., Garcia-Vallejo J. J., and Lamoree M. H. (2022). Discovery and quantification of plastic particle pollution in human blood. *Environment International*, *163*, 107199. doi: 10.1016/j.envint.2022.107199

Li L., Switzer A. D., Wang Y., Chan C.-H., Qiu Q., and Weiss R. (2018). A modest 0.5-m rise in sea level will double the tsunami hazard in Macau. *Science Advances*, *4*(8), eaat1180. doi: 10.1126/sciadv.aat1180

Ličer M., Mourre B., Troupin C., Krietemeyer A., Jansá A., and Tintoré J. (2017). Numerical study of Balearic meteotsunami generation and propagation under synthetic gravity wave forcing. *Ocean Modelling*, *111*, 38–45. doi: 10.1016/j.ocemod.2017.02.001

Linares C., Díaz J., Negev M., Martínez G. S., Debono R., and Paz S. (2020). Impacts of climate change on the public health of the Mediterranean Basin population - Current situation, projections, preparedness and adaptation. *Environmental Research*, *182*, 109107. doi: 10.1016/j.envres.2019.109107

Linares C., Paz S., Díaz J., Negev M., and Sánchez Martínez G. (2020). Health. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental Change in the Mediterranean Basin - Current Situation and Risks for the Future. First Mediterranean Assessment Report* (pp. 493–514). Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France. doi: 10.5281/zenodo.7101115

Liquete C., Piroddi C., Macías D., Druon J. N., and Zulian G. (2016). Ecosystem services sustainability in the Mediterranean Sea: Assessment of status and trends using multiple modelling approaches. *Scientific Reports*, *6*(1), 1–14. doi: 10.1038/srep34162

Liu S., Chen H., Xu X. R., Hao Q. W., Zhao J. L., and Ying G. G. (2017). Three classes of steroids in typical freshwater aquaculture farms: Comparison to marine aquaculture farms. *Science of The Total Environment*, *609*, 942–950. doi: 10.1016/j.scitotenv.2017.07.207

Llasat M. C., Del Moral A., Cortès M., and Rigo T. (2021a). Convective precipitation trends in the Spanish Mediterranean region. *Atmospheric Research*, *257*, 105581. doi: 10.1016/j.atmosres.2021.105581

Llasat M. C., Llasat-Botija M., Cortès M., Rigo T., Moral A. del, Caballero I., Iglesias A., and Jiménez J. A. (2021b). Coping with flood risk adaptation in Mediterranean countries: evidences, uncertainties, strategies and limits. *FLOODrisk 2020 - 4th European Conference on Flood Risk Management*, null-null. doi: 10.3311/floodrisk2020.12.20

Llasat M. C., Llasat-Botija M., Petrucci O., Pasqua A. A., Rosselló J., Vinet F., and Boissier L. (2013). Towards a database on societal impact of Mediterranean floods within the framework of the HYMEX project. *Natural Hazards and Earth System Sciences*, *13*(5), 1337–1350. doi: 10.5194/nhess-13-1337-2013

Llasat M. C., Llasat-Botija M., Prat M. A., Porcú F., Price C., Mugnai A., Lagouvardos K., Kotroni V., Katsanos D., Michaelides S., Yair Y., Savvidou K., and Nicolaides K. (2010). High-impact floods and flash floods in Mediterranean countries: The FLASH preliminary database. *Advances in Geosciences*, *23*, 47–55. doi: 10.5194/adgeo-23-47-2010

Lloret J., Sabatés A., Muñoz M., Demestre M., Solé I., Font T., Casadevall M., Martín P., and Gómez S. (2015). How a multidisciplinary approach involving ethnoecology, biology and fisheries can help explain the spatio-temporal changes in marine fish abundance resulting from climate change. *Global Ecology and Biogeography*, *24*(4), 448–461. doi: 10.1111/geb.12276

Löhr A., Savelli H., Beunen R., Kalz M., Ragas A., and Van Belleghem F. (2017). Solutions for global marine litter pollution. *Current Opinion in Environmental Sustainability*, *28*, 90–99. doi: 10.1016/j.cosust.2017.08.009

López-Dóriga U., and Jiménez J. A. (2020). Impact of Relative Sea-Level Rise on Low-Lying Coastal Areas of Catalonia, NW Mediterranean, Spain. *Water*, *12*(11), 3252. doi: 10.3390/w12113252

López-Dóriga U., Jiménez J. A., Valdemoro H. I., and Nicholls R. J. (2019). Impact of sea-level rise on the tourist-carrying capacity of Catalan beaches. *Ocean & Coastal Management*, *170*, 40–50. doi: 10.1016/j.ocecoaman.2018.12.028

López-Serna R., Jurado A., Vázquez-Suñé E., Carrera J., Petrović M., and Barceló D. (2013). Occurrence of 95 pharmaceuticals and transformation products in urban groundwaters underlying the metropolis of Barcelona, Spain. *Environmental Pollution*, *174*, 305–315. doi: 10.1016/j.envpol.2012.11.022

Lorito S., Tiberti M. M., Basili R., Piatanesi A., and Valensise G. (2008). Earthquake-generated tsunamis in the Mediterranean Sea: Scenarios of potential threats to Southern Italy. *Journal of Geophysical Research: Solid Earth*, *113*(1), 1301. doi: 10.1029/2007jb004943

Louati M., Saïdi H., and Zargouni F. (2015). Shoreline change assessment using remote sensing and GIS techniques: a case study of the Medjerda delta coast, Tunisia. *Arabian Journal of Geosciences*, *8*(6), 4239–4255. doi: 10.1007/s12517-014-1472-1

Lubczyńska M. J., Christophi C. A., and Lelieveld J. (2015). Heat-related cardiovascular mortality risk in Cyprus: A case-crossover study using a distributed lag non-linear model. *Environmental Health: A Global Access Science Source*, *14*(1). doi: 10.1186/s12940-015-0025-8

Luijendijk A., Hagenaars G., Ranasinghe R., Baart F., Donchyts G., and Aarninkhof S. (2018). The State of the World's Beaches. *Scientific Reports*, *8*(1), 6641. doi: 10.1038/s41598-018-24630-6

Luisetti T., Turner K., and Bateman I. (2008). *An ecosystem services approach to assess managed realignment coastal policy in England*. Working Paper - Centre for Social and Economic Research on the Global Environment, 1 edn, pp. 1-25. https://research-portal.uea.ac.uk/en/publications/an-ecosystem-services-approach-to-assess-managed-realignment-coas

Magnan A., Hamilton J., Rosselló J., Billé R., and Bujosa A. (2013). Mediterranean Tourism and Climate Change: Identifying Future Demand and Assessing Destinations' Vulnerability. In A. Navarra & L. Tubiana (Eds.), *Regional Assessment of Climate Change in the Mediterranean. Advances in Global Change Research, vol 51* (Vol. 51). Springer, Dordrecht. doi: 10.1007/978-94-007-5772-1_15

Mammì I., Rossi L., and Pranzini E. (2019). Mathematical Reconstruction of Eroded Beach Ridges at the Ombrone River Delta. *Water*, *11*(11), 2281. doi: 10.3390/w11112281

Maneas G., Makopoulou E., Bousbouras D., Berg H., and Manzoni S. (2019). Anthropogenic Changes in a Mediterranean Coastal Wetland during the Last Century—The Case of Gialova Lagoon, Messinia, Greece. *Water*, *11*(2), 350. doi: 10.3390/w11020350

Manno G., Anfuso G., Messina E., Williams A. T., Suffo M., and Liguori V. (2016). Decadal evolution of coastline armouring along the Mediterranean Andalusia littoral (South of Spain). *Ocean & Coastal Management*, *124*, 84–99. doi: 10.1016/j.ocecoaman.2016.02.007

Marampouti C., Buma A. G. J., and de Boer M. K. (2021). Mediterranean alien harmful algal blooms: origins and impacts. *Environmental Science and Pollution Research*, *28*(4), 3837–3851. doi: 10.1007/s11356-020-10383-1

Marangoz D., and Daloglu I. (2022). Development of a Water Security Index Incorporating Future Challenges. *Climate Change Management*, 313–329. doi: 10.1007/978-3-030-78566-6_15

Marras S., Cucco A., Antognarelli F., Azzurro E., Milazzo M., Bariche M., Butenschön M., Kay S., Di Bitetto M., Quattrocchi G., Sinerchia M., and Domenici P. (2015). Predicting future thermal habitat suitability of competing native and invasive fish species: from metabolic scope to oceanographic modelling. *Conservation Physiology*, *3*(1). doi: 10.1093/conphys/cou059

Marriner N., Morhange C., Flaux C., and Carayon N. (2017). Harbors and Ports, Ancient. In A. S. Gilbert (Ed.), *Encyclopedia of Geoarchaeology* (pp. 382–403). Springer Netherlands. http://link.springer.com/10.1007/978-1-4020-4409-0_119

Martinelli A., Kolokotsa D. D., and Fiorito F. (2020). Urban Heat Island in Mediterranean Coastal Cities: The Case of Bari (Italy). *Climate 2020, 8*(6), 79. doi: 10.3390/cli8060079

Martinez M., Mangano M. C., Maricchiolo G., Genovese L., Mazzola A., and Sarà G. (2018). Measuring the effects of temperature rise on Mediterranean shellfish aquaculture. *Ecological Indicators*, *88*, 71–78. doi: 10.1016/j.ecolind.2018.01.002

Martínez-Megías C., and Rico A. (2022). Biodiversity impacts by multiple anthropogenic stressors in Mediterranean coastal wetlands. *Science of The Total Environment*, *818*, 151712. doi: 10.1016/j.scitotenv.2021.151712

Mastrocicco M., and Colombani N. (2021). The Issue of Groundwater Salinization in Coastal Areas of the Mediterranean Region: A Review. *Water*, *13*(1), 90. doi: 10.3390/w13010090

MATTM (2018). *Linee Guida per la Difesa della Costa dai fenomeni di Erosione e dagli effetti dei Cambiamenti climatici. Versione 2018*. Documento elaborato dal Tavolo Nazionale sull'Erosione Costiera MATTM-Regioni con il coordinamento tecnico di ISPRA, 305 pp. https://moodle2.units.it/pluginfile.php/591581/mod_resource/content/1/TNEC_Linee-Guida-erosione-costiera_2018.pdf

MedECC (2020a). *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report* (W. Cramer, J. Guiot, & K. Marini, Eds.). Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, 632 pp. doi: 10.5281/zenodo.4768833

MedECC (2020b). Summary for Policymakers. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report*. Union for the Mediterranean, Plan Bleu, UNEP/ MAP, Marseille, France, pp 11-40. doi: 10.5281/zenodo.5513887

Mehvar S., Filatova T., Dastgheib A., de Ruyter van Steveninck E., and Ranasinghe R. (2018). Quantifying Economic Value of Coastal Ecosystem Services: A Review. *Journal of Marine Science and Engineering 2018, Vol. 6, Page 5*, *6*(1), 5. doi: 10.3390/jmse6010005

Mentaschi L., Vousdoukas M. I., Pekel J.-F., Voukouvalas E., and Feyen L. (2018). Global long-term observations of coastal erosion and accretion. *Scientific Reports*, *8*(1), 12876. doi: 10.1038/s41598-018-30904-w

Moatti, J.-P., & Thiébault, S. (Eds.). (2016). *The Mediterranean region under climate change: A scientific update - Collectif - Google Books*. Marseille: IRD Editions. doi: 10.4000/books.irdeditions.22908

Monserrat S., Ramis C., and Thorpe A. J. (1991). Large-amplitude pressure oscillations in the western Mediterranean. *Geophysical Research Letters*, *18*(2), 183–186. doi: 10.1029/91gl00234

Moragoda N., and Cohen S. (2020). Climate-induced trends in global riverine water discharge and suspended sediment dynamics in the 21st century. *Global and Planetary Change*, *191*, 103199. doi: 10.1016/j.gloplacha.2020.103199

Moreno A. (2010). Mediterranean Tourism and Climate (Change): A Survey-Based Study. *Tourism and Hospitality Planning & Development*, *7*(3), 253–265. doi: 10.1080/1479053x.2010.502384

Mouzouri M., and Irzi Z. (2011). Evolution et morphodynamique de la plaine côtière de Saïda (littoral méditerranéen du Nord-Est du Maroc) durant la période 1958–2006. *Bulletin de l'Institut Scientifique Rabat*, *33*, 65–76. http://www.israbat.ac.ma/?page_id=251#Annee_2011_Numero_33

Muresan A. N., Gaglio M., Aschonitis V., Nobili G., Castaldelli G., and Fano E. A. (2020). Structural and functional responses of macroinvertebrate communities in small wetlands of the Po delta with different and variable salinity levels. *Estuarine, Coastal and Shelf Science*, *238*, 106726. doi: 10.1016/j.ecss.2020.106726

MWO (2018). *Mediterranean Wetlands Outlook 2: Solutions for sustainable Mediterranean Wetlands,* Tour du Valat, France. https://medwet.org/wp-content/uploads/2018/10/MWO_2018_Technical-report.pdf

Navon G., Kaplan A., Avisar D., and Shenkar N. (2020). Assessing pharmaceutical contamination along the Mediterranean and Red Sea coasts of Israel: Ascidians (Chordata, Ascidiacea) as bioindicators. *Marine Pollution Bulletin*, *160*, 111510. doi: 10.1016/j.marpolbul.2020.111510

Neira M., Erguler K., Ahmady-Birgani H., DaifAllah AL-Hmoud N., Fears R., Gogos C., Hobbhahn N., Koliou M., Kostrikis L. G., Lelieveld J., Majeed A., Paz S., Rudich Y., Saad-Hussein A., Shaheen M., Tobias A., and Christophides G. (2023). Climate change and human health in the Eastern Mediterranean and middle east: Literature review, research priorities and policy suggestions. *Environmental Research*, *216*(Pt 2). doi: 10.1016/j.envres.2022.114537

Neofitou N., Syvri R., Tziantziou L., Mente E., and Vafidis D. (2020). The benthic environmental footprint of aquaculture in the Eastern Mediterranean: Organic vs conventional fish farming. *Aquaculture Research*, *51*(7), 2698–2710. doi: 10.1111/are.14609

Niavis S., and Kallioras D. (2021). The Efficiency of Tourism Sector in EU Mediterranean Coastal Regions: The Effects of Seasonality and Spatiality on Demand. *REGION*, *8*(1), 135–152. doi: 10.18335/region.v8i1.318

Nicholls R. J., and Cazenave A. (2010). Sea-Level Rise and Its Impact on Coastal Zones. *Science*, *328*(5985), 1517–1520. doi: 10.1126/science.1185782

Oppenheimer M., Oreskes N., Jamieson D., Brysse K., O'Reilly J., Shindell M., and Wazeck M. (2019). *Discerning experts: The practices of scientific assessment for environmental policy*. University of Chicago Press. doi: 10.7208/chicago/9780226602158.001.0001

Orlić M., Belušić D., Janeković I., and Pasarić M. (2010). Fresh evidence relating the great Adriatic surge of 21 June 1978 to mesoscale atmospheric forcing. *Journal of Geophysical Research*, *115*(C6), C06011. doi: 10.1029/2009jc005777

Osipov S., Chowdhury S., Crowley J. N., Tadic I., Drewnick F., Borrmann S., Eger P., Fachinger F., Fischer H., Predybaylo E., Fnais M., Harder H., Pikridas M., Vouterakos P., Pozzer A., Sciare J., Ukhov A., Stenchikov G. L., Williams J., and Lelieveld J. (2022). Severe atmospheric pollution in the Middle East is attributable to anthropogenic sources. *Communications Earth and Environment*, *3*(1), 1–10. doi: 10.1038/S43247-022-00514-6

Palatnik R. R., and Lourenço Dias Nunes P. A. (2015). Economic valuation of climate change-induced biodiversity impacts on agriculture: results from a macro-economic application to the Mediterranean basin. *Journal of Environmental Economics and Policy*, *4*(1), 45–63. doi: 10.1080/21606544.2014.963165

Pancucci-Papadopoulou M. A., Raitsos D. E., and Corsini-Foka M. (2012). Biological invasions and climatic warming: implications for south-eastern Aegean ecosystem functioning. *Journal of the Marine Biological Association of the United Kingdom*, *92*(4), 777–789. doi: 10.1017/s0025315411000981

Papadopoulos G. A., Gràcia E., Urgeles R., Sallares V., De Martini P. M., Pantosti D., González M., Yalciner A. C., Mascle J., Sakellariou D., Salamon A., Tinti S., Karastathis V., Fokaefs A., Camerlenghi A., Novikova T., and Papageorgiou A. (2014). Historical and pre-historical tsunamis in the Mediterranean and its connected seas: Geological signatures, generation mechanisms and coastal impacts. *Marine Geology*, *354*, 81–109. doi: 10.1016/j.margeo.2014.04.014

Papadopoulou M. P., Charchousi D., Tsoukala V. K., Giannakopoulos C., and Petrakis M. (2016). Water footprint assessment considering climate change effects on future agricultural production in Mediterranean region. *Desalination and Water Treatment*, *57*(5), 2232–2242. doi: 10.1080/19443994.2015.1049408

Papagiannakis A., and Ntafos K. (2021). Impact Assessment of Climate Change on Coastal Transport Systems in the Greater Thessaloniki Area. In E. G. Nathanail, G. Adamos, & I. Karakikes (Eds.), *Advances in Mobility-as-a-Service Systems* (Vol. 1278, pp. 751–759). Springer International Publishing. http://link.springer.com/10.1007/978-3-030-61075-3_73

Paprotny D., Morales-Nápoles O., Vousdoukas M. I., Jonkman S. N., and Nikulin G. (2019). Accuracy of pan-European coastal flood mapping. *Journal of Flood Risk Management*, *12*(2), e12459. doi: 10.1111/jfr3.12459

Paprotny D., Sebastian A., Morales-Nápoles O., and Jonkman S. N. (2018). Trends in flood losses in Europe over the past 150 years. *Nature Communications*, *9*(1), 1985. doi: 10.1038/s41467-018-04253-1

Paprotny D., Terefenko P., Giza A., Czapliński P., and Vousdoukas M. I. (2021). Future losses of ecosystem services due to coastal erosion in Europe. *Science of The Total Environment*, *760*, 144310. doi: 10.1016/j.scitotenv.2020.144310

Paprotny D., Vousdoukas M. I., Morales-Nápoles O., Jonkman S. N., and Feyen L. (2020). Pan-European hydrodynamic models and their ability to identify compound floods. *Natural Hazards*, *101*(3), 933–957. doi: 10.1007/s11069-020-03902-3

Pardo-Pascual J. E., and Sanjaume E. (2019). Beaches in Valencian Coast. In J. A. Morales (Ed.), *The Spanish Coastal Systems* (pp. 209–236). Springer International Publishing. http://link.springer.com/10.1007/978-3-319-93169-2_10

Park I.-S., Woon Y., Chung K.-W., Lee G., Owen J. S., Kwon W.-T., and Yun W.-T. (2014). In-depth Review of IPCC 5th Assessment Report. *Journal of Korean Society for Atmospheric Environment*, *30*(2), 188–200. doi: 10.5572/kosae.2014.30.2.188

Pauly D. (2019). A précis of Gill-Oxygen Limitation Theory (GOLT), with some Emphasis on the Eastern Mediterranean. *Mediterranean Marine Science*, *20*(4), 660–668. doi: 10.12681/mms.19285

Pedrotti M. L., Petit S., Elineau A., Bruzaud S., Crebassa J.-C., Dumontet B., Martí E., Gorsky G., and Cózar A. (2016). Changes in the Floating Plastic Pollution of the Mediterranean Sea in Relation to the Distance to Land. *PLOS ONE*, *11*(8), e0161581. doi: 10.1371/journal.pone.0161581

Peled Y., Zemah Shamir S., Shechter M., Rahav E., and Israel A. (2018). A new perspective on valuating marine climate regulation: The Israeli Mediterranean as a case study. *Ecosystem Services*, *29*, 83–90. doi: 10.1016/j.ecoser.2017.12.001

Perch-Nielsen S. L., Amelung B., and Knutti R. (2010). Future climate resources for tourism in Europe based on the daily Tourism Climatic Index. *Climatic Change*, *103*(3–4), 363–381. doi: 10.1007/s10584-009-9772-2

Perennou C., Beltrame C., Guelmami A., Tomàs Vives P., and Caessteker P. (2012). Existing areas and past changes of wetland extent in the Mediterranean region: an overview. *Ecologia Mediterranea*, *38*(2), 53–66. doi: 10.3406/ecmed.2012.1316

Perini L., Calabrese L., Salerno G., Ciavola P., and Armaroli C. (2016). Evaluation of coastal vulnerability to flooding: comparison of two different methodologies adopted by the Emilia-Romagna region (Italy). *Natural Hazards and Earth System Sciences*, *16*(1), 181–194. doi: 10.5194/nhess-16-181-2016

Perry A. H. (2000). Impacts of Climate Change on Tourism in the Mediterranean: Adaptive Responses. *SSRN Electronic Journal*. doi: 10.2139/ssrn.235082

Petrucci O., Papagiannaki K., Aceto L., Boissier L., Kotroni V., Grimalt M., Llasat M. C., Llasat-Botija M., Rosselló J., Pasqua A. A., and Vinet F. (2019). MEFF: The database of MEditerranean Flood Fatalities (1980 to 2015). *Journal of Flood Risk Management*, *12*(2), e12461. doi: 10.1111/jfr3.12461

Peyton J., Martinou A. F., Pescott O. L., Demetriou M., Adriaens T., Arianoutsou M., Bazos I., Bean C. W., Booy O., Botham M., Britton J. R., Cervia J. L., Charilaou P., Chartosia N., Dean H. J., Delipetrou P., Dimitriou A. C., Dörflinger G., Fawcett J., … Roy H. E. (2019). Horizon scanning for invasive alien species with the potential to threaten biodiversity and human health on a Mediterranean island. *Biological Invasions*, *21*(6), 2107–2125. doi: 10.1007/s10530-019-01961-7

Piscart C., Mermillod-Blondin F., Maazouzi C., Merigoux S., and Marmonier P. (2011). Potential impact of invasive amphipods on leaf litter recycling in aquatic ecosystems. *Biological Invasions*, *13*(12), 2861–2868. doi: 10.1007/S10530-011-9969-y

Plan Bleu (2022). *State of Play of Tourism in the Mediterranean.* Interreg Med Sustainable Tourism Community project. https://planbleu.org/en/publications/state-of-play-of-tourism-in-the-mediterranean

Ponti L., Gutierrez A. P., Ruti P. M., and Dell'Aquila A. (2014). Fine-scale ecological and economic assessment of climate change on olive in the Mediterranean Basin reveals winners and losers. *Proceedings of the National Academy of Sciences*, *111*(15), 5598–5603. doi: 10.1073/pnas.1314437111

Pool S., Francés F., Garcia-Prats A., Pulido-Velazquez M., Sanchis-Ibor C., Schirmer M., Yang H., and Jiménez-Martínez J. (2021). From Flood to Drip Irrigation Under Climate Change: Impacts on Evapotranspiration and Groundwater Recharge in the Mediterranean Region of Valencia (Spain). *Earth's Future*, *9*(5). doi: 10.1029/2020ef001859

Prado P., Ibáñez C., Chen L., and Caiola N. (2022). Feeding Habits and Short-Term Mobility Patterns of Blue Crab, Callinectes sapidus, Across Invaded Habitats of the Ebro Delta Subjected to Contrasting Salinity. *Estuaries and Coasts*, *45*(3), 839–855. doi: 10.1007/s12237-021-01004-2

Prado P., Peñas A., Ibáñez C., Cabanes P., Jornet L., Álvarez N., and Caiola N. (2020). Prey size and species preferences in the invasive blue crab, Callinectes sapidus: Potential effects in marine and freshwater ecosystems. *Estuarine, Coastal and Shelf Science*, *245*, 106997. doi: 10.1016/j.ecss.2020.106997

Pranzini E. (2018). Shore protection in Italy: From hard to soft engineering … and back. *Ocean & Coastal Management*, *156*, 43–57. doi: 10.1016/j.ocecoaman.2017.04.018

Precali R., Giani M., Marini M., Grilli F., Ferrari C. R., Pečar O., and Paschini E. (2005). Mucilaginous aggregates in the northern Adriatic in the period 1999–2002: Typology and distribution. *Science of The Total Environment*, *353*(1–3), 10–23. doi: 10.1016/j.scitotenv.2005.09.066

Przeslawski R., Byrne M., and Mellin C. (2015). A review and meta-analysis of the effects of multiple abiotic stressors on marine embryos and larvae. *Global Change Biology*, *21*(6), 2122–2140. doi: 10.1111/gcb.12833

Pulido-Velazquez D., Renau-Pruñonosa A., Llopis-Albert C., Morell I., Collados-Lara A.-J., Senent-Aparicio J., and Baena-Ruiz L. (2018). Integrated assessment of future potential global change scenarios and their hydrological impacts in coastal aquifers – a new tool to analyse management alternatives in the Plana Oropesa-Torreblanca aquifer. *Hydrology and Earth System Sciences*, *22*(5), 3053–3074. doi: 10.5194/hess-22-3053-2018

Pulighe G., Lupia F., Chen H., and Yin H. (2021). Modeling Climate Change Impacts on Water Balance of a Mediterranean Watershed Using SWAT+. *Hydrology*, *8*(4), 157. doi: 10.3390/hydrology8040157

Purcell J. E. (2012). Jellyfish and Ctenophore Blooms Coincide with Human Proliferations and Environmental Perturbations. *Annual Review of Marine Science*, *4*(1), 209–235. doi: 10.1146/annurev-marine-120709-142751

Pyrgou A., and Santamouris M. (2018). Increasing Probability of Heat-Related Mortality in a Mediterranean City Due to Urban Warming. *International Journal of Environmental Research and Public Health 2018, Vol. 15, Page 1571*, *15*(8), 1571. doi: 10.3390/ijerph15081571

Rainbow P. S. (2002). Trace metal concentrations in aquatic invertebrates: why and so what? *Environmental Pollution*, *120*(3), 497–507. doi: 10.1016/s0269-7491(02)00238-5

Ramajo L., Lagos N. A., and Duarte C. M. (2019). Seagrass Posidonia oceanica diel pH fluctuations reduce the mortality of epiphytic forams under experimental ocean acidification. *Marine Pollution Bulletin*, *146*, 247–254. doi: 10.1016/j.marpolbul.2019.06.011

Ramírez-Cuesta J. M., Rodríguez-Santalla I., Gracia F. J., Sánchez-García M. J., and Barrio-Parra F. (2016). Application of change detection techniques in geomorphological evolution of coastal areas. Example: Mouth of the River Ebro (period 1957–2013). *Applied Geography*, *75*, 12–27. doi: 10.1016/j.apgeog.2016.07.015

Ranasinghe R. (2016). Assessing climate change impacts on open sandy coasts: A review. *Earth-Science Reviews*, *160*, 320–332. doi: 10.1016/j.earscirev.2016.07.011

Ranasinghe R., Callaghan D., and Stive M. J. F. (2012). Estimating coastal recession due to sea level rise: beyond the Bruun rule. *Climatic Change*, *110*(3–4), 561–574. doi: 10.1007/s10584-011-0107-8

Rani R., Sharma P., Kumar R., and Hajam Y. A. (2022). Effects of heavy metals and pesticides on fish. *Bacterial Fish Diseases*, 59–86. doi: 10.1016/B978-0-323-85624-9.00016-6

Refaat M. M., and Eldeberky Y. (2016). Assessment of Coastal Inundation due to Sea-Level Rise along the Mediterranean Coast of Egypt. *Marine Geodesy*, *39*(3–4), 290–304. doi: 10.1080/01490419.2016.1189471

Reimann L., Jones B., Bieker N., Wolff C., Aerts J. C. J. H., and Vafeidis A. T. (2023). Exploring spatial feedbacks between adaptation policies and internal migration patterns due to sea-level rise. *Nature Communications 2023 14:1*, *14*(1), 1–14. doi: 10.1038/s41467-023-38278-y

Reimann L., Merkens J. L., and Vafeidis A. T. (2018). Regionalized Shared Socioeconomic Pathways: narratives and spatial population projections for the Mediterranean coastal zone. *Regional Environmental Change*, *18*(1). doi: 10.1007/s10113-017-1189-2

Reimann L., Vafeidis A. T., Brown S., Hinkel J., and Tol R. S. J. (2018). Mediterranean UNESCO World Heritage at risk from coastal flooding and erosion due to sea-level rise. *Nature Communications*, *9*(1). doi: 10.1038/s41467-018-06645-9

Renau-Pruñonosa A., Morell I., and Pulido-Velazquez D. (2016). A Methodology to Analyse and Assess Pumping Management Strategies in Coastal Aquifers to Avoid Degradation Due to Seawater Intrusion Problems. *Water Resources Management*, *30*(13), 4823–4837. doi: 10.1007/s11269-016-1455-y

Reyes F., Gosme M., Wolz K. J., Lecomte I., and Dupraz C. (2021). Alley cropping mitigates the impacts of climate change on a wheat crop in a mediterranean environment: A biophysical model-based assessment. *Agriculture (Switzerland)*, *11*(4), 356. doi: 10.3390/agriculture11040356/s1

Riccaboni A., Antonelli M., and Stanghellini G. (2022). Partnership for Research and Innovation in the Mediterranean Area and the Promotion of a Nexus Approach. In L. Cavalli & S. Vergalli (Eds.), *Connecting the Sustainable Development Goals: The WEF Nexus* (pp. 13–19). Springer International Publishing. https://link.springer.com/10.1007/978-3-031-01336-2_2

Richir, J., and Gobert, S. (2016). Trace Elements in Marine Environments : Occurrence, Threats and Monitoring with Special Focus on the Costal Mediterranean. *Journal of Environmental and Analytical Toxicology*, *6:1*(01). doi: 10.4172/2161-0525.1000349

Rick T., Ontiveros M. Á. C., Jerardino A., Mariotti A., Méndez C., and Williams A. N. (2020). Human-environmental interactions in Mediterranean climate regions from the Pleistocene to the Anthropocene. *Anthropocene*, *31*, 100253. doi: 10.1016/j.ancene.2020.100253

Ridgway J., and Shimmield G. (2002). Estuaries as Repositories of Historical Contamination and their Impact on Shelf Seas. *Estuarine, Coastal and Shelf Science*, *55*(6), 903–928. doi: 10.1006/ecss.2002.1035

Rilov G., Peleg O., and Guy-Haim T. (2019). The Restructuring of Levant Reefs by Aliens, Ocean Warming and Overfishing. In S. J. Hawkins, K. Bohn, L. B. Firth, & G. A. Williams (Eds.), *Interactions in the Marine Benthos: Global Patterns and Processes* (pp. 214–236). Cambridge University Press. doi: 10.1017/9781108235792.010

Rinaldi A., Vollenweider R. A., Montanari G., Ferrari C. R., and Ghetti A. (1995). Mucilages in Italian seas: the Adriatic and Tyrrhenian Seas, 1988–1991. *Science of The Total Environment*, *165*(1–3), 165–183. doi: 10.1016/0048-9697(95)04550-K

Rivetti I., Fraschetti S., Lionello P., Zambianchi E., and Boero F. (2014). Global Warming and Mass Mortalities of Benthic Invertebrates in the Mediterranean Sea. *PLOS ONE*, *9*(12), e115655. doi: 10.1371/journal.pone.0115655

Rizzetto F. (2020). Effects of Climate Change on the Morphological Stability of the Mediterranean Coasts: Consequences for Tourism. *Climate Change Management*, 761–775. doi: 10.1007/978-3-030-37425-9_38

Rizzo A., Vandelli V., Gauci C., Buhagiar G., Micallef A. S., and Soldati M. (2022). Potential Sea Level Rise Inundation in the Mediterranean: From Susceptibility Assessment to Risk Scenarios for Policy Action. *Water*, *14*(3), 416. doi: 10.3390/w14030416

Rodella I., Corbau C., Simeoni U., and Utizi K. (2017). Assessment of the relationship between geomorphological evolution, carrying capacity and users' perception: Case studies in Emilia-Romagna (Italy). *Tourism Management*, *59*, 7–22. doi: 10.1016/j.tourman.2016.07.009

Rodrigo-Comino J., Salvia R., Quaranta G., Cudlín P., Salvati L., and Gimenez-Morera A. (2021). Climate Aridity and the Geographical Shift of Olive Trees in a Mediterranean Northern Region. *Climate*, *9*(4), 64. https://doi.org/10.3390/cli9040064

Rodrigues L. C., van den Bergh J. C. J. M., and Ghermandi A. (2013). Socio-economic impacts of ocean acidification in the Mediterranean Sea. *Marine Policy*, *38*, 447–456. doi: 10.1016/j.marpol.2012.07.005

Rodríguez-Santalla I., and Navarro N. (2021). Main Threats in Mediterranean Coastal Wetlands. The Ebro Delta Case. *Journal of Marine Science and Engineering*, *9*(11), 1190. doi: 10.3390/jmse9111190

Roebeling P. C., Costa L., Magalhães-Filho L., and Tekken V. (2013). Ecosystem service value losses from coastal erosion in Europe: Historical trends and future projections. *Journal of Coastal Conservation*, *17*(3), 389–395. doi: 10.1007/s11852-013-0235-6

Rosa R., Marques A., and Nunes M. L. (2012). Impact of climate change in Mediterranean aquaculture. *Reviews in Aquaculture*, *4*(3), 163–177. doi: 10.1111/J.1753-5131.2012.01071.x

Rosa R., Marques A., and Nunes M. L. (2014). Mediterranean Aquaculture in a Changing Climate. In S. Goffredo & Z. Dubinsky (Eds.), *The Mediterranean Sea* (pp. 605–616). Springer Netherlands. https://link.springer.com/10.1007/978-94-007-6704-1_37

Rosenthal E., Vinokurov A., Ronen D., Magaritz M., and Moshkovitz S. (1992). Anthropogenically induced salinization of groundwater: A case study from the Coastal Plain aquifer of Israel. *Journal of Contaminant Hydrology*, *11*(1–2), 149–171. doi: 10.1016/0169-7722(92)90038-g

Roukounis C. N., and Tsihrintzis V. A. (2022). Indices of Coastal Vulnerability to Climate Change: a Review. *Environmental Processes*, *9*(2), 1–25. doi: 10.1007/S40710-022-00577-9

Rovira J., Domingo J. L., and Schuhmacher M. (2020). Air quality, health impacts and burden of disease due to air pollution (PM10, PM2.5, NO2 and O3): Application of AirQ+ model to the Camp de Tarragona County (Catalonia, Spain). *Science of The Total Environment*, *703*, 135538. doi: 10.1016/j.scitotenv.2019.135538

Roy H. E., Hesketh H., Purse B. V., Eilenberg J., Santini A., Scalera R., Stentiford G. D., Adriaens T., Bacela-Spychalska K., Bass D., Beckmann K. M., Bessell P., Bojko J., Booy O., Cardoso A. C., Essl F., Groom Q., Harrower C., Kleespies R., … Dunn A. M. (2017). Alien Pathogens on the Horizon: Opportunities for Predicting their Threat to Wildlife. *Conservation Letters*, *10*(4), 477–484. doi: 10.1111/conl.12297

Rutty M., and Scott D. (2010). Will the Mediterranean Become "Too Hot" for Tourism? A Reassessment. *Tourism and Hospitality Planning & Development*, *7*(3), 267–281. doi: 10.1080/1479053x2010.502386

Sabatier F., and Suanez S. (2003). Evolution of the Rhône delta coast since the end of the 19th century / Cinématique du littoral du delta du Rhône depuis la fin du XIXe siècle. *Géomorphologie relief processus environnement*, *9*(4), 283–300. doi: 10.3406/morfo.2003.1191

Saber M., Abdrabo K. I., Habiba O. M., Kantosh S. A., and Sumi T. (2020). Impacts of Triple Factors on Flash Flood Vulnerability in Egypt: Urban Growth, Extreme Climate, and Mismanagement. *Geosciences 2020, Vol. 10, Page 24*, *10*(1), 24. doi: 10.3390/geosciences10010024

Sadutto D., Andreu V., Ilo T., Akkanen J., and Picó Y. (2021). Pharmaceuticals and personal care products in a Mediterranean coastal wetland: Impact of anthropogenic and spatial factors and environmental risk assessment. *Environmental Pollution*, *271*, 116353. doi: 10.1016/j.envpol.2020.116353

Salomidi M., Katsanevakis S., Borja Á., Braeckman U., Damalas D., Galparsoro I., Mifsud R., Mirto S., Pascual M., Pipitone C., Rabaut M., Todorova V., Vassilopoulou V., and Fernández T. V. (2012). Assessment of goods and services, vulnerability, and conservation status of European seabed biotopes: a stepping stone towards ecosystem-based marine spatial management. *Mediterranean Marine Science*, *13*(1), 49–88. doi: 10.12681/mms.23

Sánchez-Arcilla A., Mösso C., Sierra J. P., Mestres M., Harzallah A., Senouci M., and El Raey M. (2011). Climatic drivers of potential hazards in Mediterranean coasts. *Regional Environmental Change*, *11*(3), 617–636. doi: 10.1007/s10113-010-0193-6

Sánchez-Arcilla A., Sierra J. P., Brown S., Casas-Prat M., Nicholls R. J., Lionello P., and Conte D. (2016). A review of potential physical impacts on harbours in the Mediterranean Sea under climate change. *Regional Environmental Change*, *16*(8), 2471–2484. doi: 10.1007/s10113-016-0972-9

Santillán D., Garrote L., Iglesias A., and Sotes V. (2020). Climate change risks and adaptation: new indicators for Mediterranean viticulture. *Mitigation and Adaptation Strategies for Global Change*, *25*(5), 881–899. doi: 10.1007/s11027-019-09899-w

Sanuy M., Rigo T., Jiménez J. A., and Llasat M. C. (2021). Classifying compound coastal storm and heavy rainfall events in the north-western Spanish Mediterranean. *Hydrology and Earth System Sciences*, *25*(6), 3759–3781. doi: 10.5194/hess-25-3759-2021

Sarkar N., Rizzo A., Vandelli V., and Soldati M. (2022). A Literature Review of Climate-Related Coastal Risks in the Mediterranean, a Climate Change Hotspot. *Sustainability (Switzerland)*, *14*(23), 15994. doi: 10.3390/su142315994

Sarsour A., and Nagabhatla N. (2022). Options and Strategies for Planning Water and Climate Security in the Occupied Palestinian Territories. *Water*, *14*(21), 3418. doi: 10.3390/w14213418

Sartini L., Besio G., and Cassola F. (2017). Spatio-temporal modelling of extreme wave heights in the Mediterranean Sea. *Ocean Modelling*, *117*, 52–69. doi: 10.1016/j.ocemod.2017.07.001

Satta A., Puddu M., Venturini S., and Giupponi C. (2017). Assessment of coastal risks to climate change related impacts at the regional scale: The case of the Mediterranean region. *International Journal of Disaster Risk Reduction*, *24*(June), 284–296. doi: 10.1016/j.ijdrr.2017.06.018

Savun-Heki-Moğlu B., Erbay B., Burak Z. S., and Gazi-Oğlu C. (2021). A Comparative MCDM Analysis of Potential Short-Term Measures for Dealing with Mucilage Problem in the Sea of Marmara. *International Journal of Environment and Geoinformatics*, *8*(4), 572–580. doi: 10.30897/ijegeo.1026107

Schuyler Q. A., Wilcox C., Townsend K. A., Wedemeyer-Strombel K. R., Balazs G., Van Sebille E., and Hardesty B. D. (2016). Risk analysis reveals global hotspots for marine debris ingestion by sea turtles. *Global Change Biology*, *22*(2), 567–576. doi: 10.1111/gcb.13078

Scicchitano G., Scardino G., Monaco C., Piscitelli A., Milella M., De Giosa F., and Mastronuzzi G. (2021). Comparing impact effects of common storms and Medicanes along the coast of south-eastern Sicily. *Marine Geology*, *439*, 106556. doi: 10.1016/j.margeo.2021.106556

Sedrati M., and Anthony E. J. (2007). A brief overview of plan-shape disequilibrium in embayed beaches: Tangier bay (Morocco). *Méditerranée*, *108*, 125–130. doi: 10.4000/mediterranee.190

Seetanah B., and Fauzel S. (2019). Investigating the impact of climate change on the tourism sector: evidence from a sample of island economies. *Tourism Review*, *74*(2), 223–232. doi: 10.1108/tr-12-2017-0204

Sefelnasr A., and Sherif M. (2014). Impacts of Seawater Rise on Seawater Intrusion in the Nile Delta Aquifer, Egypt. *Groundwater*, *52*(2), 264–276. doi: 10.1111/gwat.12058

Šepić J., Rabinovich A. B., and Sytov V. N. (2018a). Odessa Tsunami of 27 June 2014: Observations and Numerical Modelling. *Pure and Applied Geophysics*, *175*(4), 1545–1572. doi: 10.1007/s00024-017-1729-1

Šepić J., Vilibić I., and Monserrat S. (2016). Quantifying the probability of meteotsunami occurrence from synoptic atmospheric patterns. *Geophysical Research Letters*, *43*(19). doi: 10.1002/2016gl070754

Šepić J., Vilibić I., Rabinovich A., and Tinti S. (2018b). Meteotsunami ("Marrobbio") of 25–26 June 2014 on the Southwestern Coast of Sicily, Italy. *Pure and Applied Geophysics*, *175*(4), 1573–1593. doi: 10.1007/s00024-018-1827-8

Sharaan M., and Udo K. (2020). Projections of future beach loss along the mediterranean coastline of Egypt due to sea-level rise. *Applied Ocean Research*, *94*, 101972. doi: 10.1016/j.apor.2019.101972

Sierra J. P., Casanovas I., Mösso C., Mestres M., and Sánchez-Arcilla A. (2016). Vulnerability of Catalan (NW Mediterranean) ports to wave overtopping due to different scenarios of sea level rise. *Regional Environmental Change*, *16*(5), 1457–1468. doi: 10.1007/s10113-015-0879-x

Silva J., Sharon Y., Santos R., and Beer S. (2009). Measuring seagrass photosynthesis: methods and applications. *Aquatic Biology*, *7*, 127–141. doi: 10.3354/ab00173

Sinclair M., and Valdimarsson G. (2001). Responsible Fisheries in the Marine Ecosystem. In M. Sinclair & G. Valdimarsson (Eds.), *Reikjavik: Conference on Responsible Fisheries in the Marine Ecosystem*. CABI Publishing, 426 pp. doi: 10.1016/j.ress.2008.10.011

Snoussi M., Niazi S., Khouakhi A., and Raji O. (2010). Climate change and sea level rise: a GIS-based vulnerability and impact assessement, the case of the Moroccan coast. In M. Maanan & M. Robin (Eds.), *Geomatic Solutions For Coastal Environments* . Nova Science Publishers, Inc. https://novapublishers.com/shop/geomatic-solutions-for-coastal-environments/

Snoussi M., Ouchani T., Khouakhi A., and Niang-Diop I. (2009). Impacts of sea-level rise on the Moroccan coastal zone: Quantifying coastal erosion and flooding in the Tangier Bay. *Geomorphology*, *107*(1–2), 32–40. doi: 10.1016/j.geomorph.2006.07.043

Snoussi M., Ouchani T., and Niazi S. (2008). Vulnerability assessment of the impact of sea-level rise and flooding on the Moroccan coast: The case of the Mediterranean eastern zone. *Estuarine, Coastal and Shelf Science*, *77*(2), 206–213. doi: 10.1016/j.ecss.2007.09.024

Sola F., Vallejos A., Moreno L., López Geta J. A., and Pulido Bosch A. (2013). Identification of hydrogeochemical process linked to marine intrusion induced by pumping of a semiconfined mediterranean coastal aquifer. *International Journal of Environmental Science and Technology*, *10*(1), 63–76. doi: 10.1007/s13762-012-0087-x

Spezzano P. (2021). Mapping the susceptibility of UNESCO World Cultural Heritage sites in Europe to ambient (outdoor) air pollution. *Science of The Total Environment*, *754*, 142345. doi: 10.1016/j.scitotenv.2020.142345

Stavrakidis-Zachou O., Lika K., Anastasiadis P., and Papandroulakis N. (2021). Projecting climate change impacts on Mediterranean finfish production: a case study in Greece. *Climatic Change*, *165*(3–4), 1–18. doi: 10.1007/s10584-021-03096-y

Stergiou K. I., Somarakis S., Triantafyllou G., Tsiaras K. P., Giannoulaki M., Petihakis G., Machias A., and Tsikliras A. C. (2016). Trends in productivity and biomass yields in the Mediterranean Sea Large Marine Ecosystem during climate change. *Environmental Development*, *17*, 57–74. doi: 10.1016/j.envdev.2015.09.001

Stratigea A., Leka A., and Nicolaides C. (2017). *Small and Medium-Sized Cities and Insular Communities in the Mediterranean: Coping with Sustainability Challenges in the Smart City Context*. 3–29. doi: 10.1007/978-3-319-54558-5_1

Syvitski J., Ángel J. R., Saito Y., Overeem I., Vörösmarty C. J., Wang H., and Olago D. (2022). Earth's sediment cycle during the Anthropocene. *Nature Reviews Earth & Environment*, *3*(3), 179–196. doi: 10.1038/s43017-021-00253-w

Syvitski J. P. M., Vörösmarty C. J., Kettner A. J., and Green P. (2005). Impact of Humans on the Flux of Terrestrial Sediment to the Global Coastal Ocean. *Science*, *308*(5720), 376–380. doi: 10.1126/science.1109454

Taylor M. L., Gwinnett C., Robinson L. F., and Woodall L. C. (2016). Plastic microfibre ingestion by deep-sea organisms. *Scientific Reports*, *6*(1), 33997. doi: 10.1038/srep33997

Taylor N. G., Grillas P., Al Hreisha H., Balkız Ö., Borie M., Boutron O., Catita A., Champagnon J., Cherif S., Çiçek K., Costa L. T., Dakki M., Fois M., Galewski T., Galli A., Georgiadis N. M., Green A. J., Hermoso V., Kapedani R., … Sutherland W. J. (2021). The future for Mediterranean wetlands: 50 key issues and 50 important conservation research questions. *Regional Environmental Change*, *21*(2), 33. doi: 10.1007/s10113-020-01743-1

Temmerman S., Horstman E. M., Krauss K. W., Mullarney J. C., Pelckmans I., and Schoutens K. (2023). Marshes and Mangroves as Nature-Based Coastal Storm Buffers. *Annual Review of Marine Science*, *15*(1), 95–118. doi: 10.1146/annurev-marine-040422-092951

Temmerman S., Moonen P., Schoelynck J., Govers G., and Bouma T. J. (2012). Impact of vegetation die-off on spatial flow patterns over a tidal marsh. *Geophysical Research Letters*, *39*(3). doi: 10.1029/2011gl050502

Terefenko P., Giza A., Paprotny D., Kubicki A., and Winowski M. (2018a). Cliff Retreat Induced by Series of Storms at Międzyzdroje (Poland). *Journal of Coastal Research*, *85*, 181–185. doi: 10.2112/SI85-037.1

Terefenko P., Paprotny D., Giza A., Morales-Nápoles O., Kubicki A., and Walczakiewicz S. (2019). Monitoring Cliff Erosion with LiDAR Surveys and Bayesian Network-based Data Analysis. *Remote Sensing*, *11*(7), 843. doi: 10.3390/rs11070843

Terefenko P., Zelaya Wziątek D., Dalyot S., Boski T., and Pinheiro Lima-Filho F. (2018b). A High-Precision LiDAR-Based Method for Surveying and Classifying Coastal Notches. *ISPRS International Journal of Geo-Information*, *7*(8), 295. doi: 10.3390/ijgi7080295

Thiéblemont R., Le Cozannet G., Toimil A., Meyssignac B., and Losada I. J. (2019). Likely and High-End Impacts of Regional Sea-Level Rise on the Shoreline Change of European Sandy Coasts Under a High Greenhouse Gas Emissions Scenario. *Water*, *11*(12), 2607. doi: 10.3390/w11122607

Toimil A., Camus P., Losada I. J., Le Cozannet G., Nicholls R. J., Idier D., and Maspataud A. (2020). Climate change-driven coastal erosion modelling in temperate sandy beaches: Methods and uncertainty treatment. *Earth-Science Reviews*, *202*, 103110. doi: 10.1016/j.earscirev.2020.103110

Toomey T., Amores A., Marcos M., Orfila A., and Romero R. (2022). Coastal Hazards of Tropical-Like Cyclones Over the Mediterranean Sea. *Journal of Geophysical Research: Oceans*, *127*(2). doi: 10.1029/2021jc017964

Torresan S., Critto A., Rizzi J., and Marcomini A. (2012). Assessment of coastal vulnerability to climate change hazards at the regional scale: The case study of the North Adriatic Sea. *Natural Hazards and Earth System Science*, *12*(7), 2347–2368. doi: 10.5194/nhess-12-2347-2012

Toth E., Bragalli C., and Neri M. (2018). Assessing the significance of tourism and climate on residential water demand: Panel-data analysis and non-linear modelling of monthly water consumptions. *Environmental Modelling and Software*, *103*. doi: 10.1016/j.envsoft.2018.01.011

Tramblay Y., Llasat M. C., Randin C., and Coppola E. (2020). Climate change impacts on water resources in the Mediterranean. *Regional Environmental Change*, *20*(3), 83, s10113-020-01665-y. doi: 10.1007/s10113-020-01665-y

Tramblay Y., Mimeau L., Neppel L., Vinet F., and Sauquet E. (2019). Detection and attribution of flood trends in Mediterranean basins. *Hydrology and Earth System Sciences*, *23*(11), 4419–4431. doi: 10.5194/hess-23-4419-2019

Tramblay Y., and Somot S. (2018). Future evolution of extreme precipitation in the Mediterranean. *Climatic Change*, *151*(2), 289–302. doi: 10.1007/s10584-018-2300-5

Treppiedi D., Cipolla G., and Noto L. V. (2023). Convective precipitation over a Mediterranean area: From identification to trend analysis starting from high-resolution rain gauges data. *International Journal of Climatology*, *43*(1), 293–313. doi: 10.1002/joc.7758

Tsikliras A. C., Dinouli A., and Tsalkou E. (2013). Exploitation trends of the Mediterranean and Black Sea fisheries. *Acta Adriatica*, *54*(2), 273–282. https://hrcak.srce.hr/117688

Tsikliras A. C., Dinouli A., Tsiros V. Z., and Tsalkou E. (2015). The Mediterranean and Black Sea Fisheries at Risk from Overexploitation. *PLoS ONE*, *10*(3), e0121188. doi: 10.1371/journal.pone.0121188

Tsikliras A. C., and Stergiou K. I. (2014). Mean temperature of the catch increases quickly in the Mediterranean Sea. *Marine Ecology Progress Series*, *515*, 281–284. doi: 10.3354/meps11005

Tsirintanis K., Azzurro E., Crocetta F., Dimiza M., Froglia C., Gerovasileiou V., Langeneck J., Mancinelli G., Rosso A., and Stern N. (2022). Bioinvasion impacts on biodiversity, ecosystem services, and human health in the Mediterranean Sea. *Aquatic Invasions*, *17*(3), 308–352. doi: 10.3391/ai.2022.17.3.01

Tsoukala V. K., Katsardi V., Hadjibiros K., and Moutzouris C. I. (2015). Beach Erosion and Consequential Impacts Due to the Presence of Harbours in Sandy Beaches in Greece and Cyprus. *Environmental Processes*, *2*(S1), 55–71. doi: 10.1007/s40710-015-0096-0

Tuel A., and Eltahir E. A. B. (2020). Why Is the Mediterranean a Climate Change Hot Spot? *Journal of Climate*, *33*(14), 5829–5843. doi: 10.1175/jcli-d-19-0910.1

Ülker D., and Baltaoğlu S. (2018). Ship born oil pollution in Turkish straits sea area and MARPOL 73/78. *Oil Spill along the Turkish Straits*, *363*.

Ülker D., Burak S., Balas L., and Çağlar N. (2022). Mathematical modelling of oil spill weathering processes for contingency planning in Izmit Bay. *Regional Studies in Marine Science*, *50*. doi: 10.1016/j.rsma.2021.102155

Ünal V., and Göncüoğlu Bodur H. (2017). The socio-economic impacts of the silver-cheeked toadfish on small-scale fishers: A comparative study from the Turkish coast. *Su Ürünleri Dergisi*, *34*(2), 119–127. doi: 10.12714/egejfas.2017.34.2.01

UNEP/MAP (1991). *Jellyfish blooms in the Mediterranean. Proceedings of the 2nd Workshop on Jellyfish in the Mediterranean Sea*. UNEP/MAP. https://wedocs.unep.org/xmlui/handle/20.500.11822/425

UNEP/MAP (2016). *Mediterranean Strategy for Sustainable Development 2016-2025*. Valbonne. Plan Bleu, Regional Activity Centre. https://wedocs.unep.org/bitstream/handle/20.500.11822/7097/mssd_2016_2025_eng.pdf

UNEP/MAP (2023). *Mediterranean Quality Status Report: The state of the Mediterranean Sea and Coast from 2018-2023*. Athens. https://wedocs.unep.org/handle/20.500.11822/46733

UNEP/MAP, and PAP/RAC (2008). *Protocol on Integrated Coastal Zone Management in the Mediterranean*. UNEP/MAP/RAC-PAP. https://wedocs.unep.org/xmlui/handle/20.500.11822/1747

UNEP/MAP, and Plan Bleu (2020). *State of the Environment and Development in the Mediterranean*. Nairobi. https://planbleu.org/wp-content/uploads/2021/04/SoED_full-report.pdf

Vacchi M., Joyse K. M., Kopp R. E., Marriner N., Kaniewski D., and Rovere A. (2021). Climate pacing of millennial sea-level change variability in the central and western Mediterranean. *Nature Communications*, *12*(1), 4013. doi: 10.1038/s41467-021-24250-1

Vafeidis A., Abdulla A., Bondeau A., Brotons L., Ludwig R., Portman M., Reimann L., Vousdoukas M., and Xoplaki E. (2020). Managing Future Risks and Building Socio-Ecological Resilience. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental change in the Mediterranean Basin - Current Situations and Risks for the Future*. Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, pp. 539-588. doi: 10.5281/zenodo.7101119

Valdemoro H. I., and Jiménez J. A. (2006). The Influence of Shoreline Dynamics on the Use and Exploitation of Mediterranean Tourist Beaches. *Coastal Management*, *34*(4), 405–423. doi: 10.1080/08920750600860324

Vareda J. P., Valente A. J. M., and Durães L. (2019). Assessment of heavy metal pollution from anthropogenic activities and remediation strategies: A review. *Journal of Environmental Management*, *246*, 101–118. doi: 10.1016/j.jenvman.2019.05.126

Vasilakopoulos P., Maravelias C. D., and Tserpes G. (2014). The Alarming Decline of Mediterranean Fish Stocks. *Current Biology*, *24*(14), 1643–1648. doi: 10.1016/j.cub.2014.05.070

Vázquez-Luis M., Álvarez E., Barrajón A., García-March J. R., Grau A., Hendriks I. E., Jiménez S., Kersting D., Moreno D., Pérez M., Ruiz J. M., Sánchez J., Villalba A., and Deudero S. (2017). S.O.S. Pinna nobilis: A mass mortality event in western Mediterranean Sea. *Frontiers in Marine Science*, *4*(JUL), 279336. doi: 10.3389/fmars.2017.00220

Vecchio, Anzidei, Serpelloni, and Florindo. (2019). Natural Variability and Vertical Land Motion Contributions in the Mediterranean Sea-Level Records over the Last Two Centuries and Projections for 2100. *Water*, *11*(7), 1480. doi: 10.3390/w11071480

Vezzulli L., Previati M., Pruzzo C., Marchese A., Bourne D. G., and Cerrano C. (2010). Vibrio infections triggering mass mortality events in a warming Mediterranean Sea. *Environmental Microbiology*, *12*(7), 2007–2019. doi: 10.1111/J.1462-2920.2010.02209.x

Vilas-Boas J. A., Arenas-Sánchez A., Vighi M., Romo S., Van den Brink P. J., Pedroso Dias R. J., and Rico A. (2021). Multiple stressors in Mediterranean coastal wetland ecosystems: Influence of salinity and an insecticide on zooplankton communities under different temperature conditions. *Chemosphere*, *269*, 129381. doi: 10.1016/j.chemosphere.2020.129381

Vilibić I., Denamiel C., Zemunik P., and Monserrat S. (2020). The Mediterranean and Black Sea meteotsunamis: an overview. *Natural Hazards 2020 106:2*, *106*(2), 1223–1267. doi: 10.1007/S11069-020-04306-z

Vilibić I., Denamiel C., Zemunik P., and Monserrat S. (2021). The Mediterranean and Black Sea meteotsunamis: an overview. *Natural Hazards*, *106*(2), 1223–1267. doi: 10.1007/s11069-020-04306-z

Vilibić I., Monserrat S., Rabinovich A., and Mihanović H. (2008). Numerical Modelling of the Destructive Meteotsunami of 15 June, 2006 on the Coast of the Balearic Islands. *Pure and Applied Geophysics*, *165*(11–12), 2169–2195. doi: 10.1007/s00024-008-0426-5

Vousdoukas M. I., Mentaschi L., Voukouvalas E., Bianchi A., Dottori F., and Feyen L. (2018). Climatic and socioeconomic controls of future coastal flood risk in Europe. *Nature Climate Change*, *8*(9), 776–780. doi: 10.1038/s41558-018-0260-4

Vousdoukas M. I., Mentaschi L., Voukouvalas E., Verlaan M., Jevrejeva S., Jackson L. P., and Feyen L. (2018). Global probabilistic projections of extreme sea levels show intensification of coastal flood hazard. *Nature Communications*, *9*(1), 2360. doi: 10.1038/s41467-018-04692-w

Vousdoukas M. I., Ranasinghe R., Mentaschi L., Plomaritis T. A., Athanasiou P., Luijendijk A., and Feyen L. (2020). Sandy coastlines under threat of erosion. *Nature Climate Change*, *10*(3), 260–263. doi: 10.1038/s41558-020-0697-0

Vrontisi Z., Charalampidis I., Lehr U., Meyer M., Paroussos L., Lutz C., Lam-González Y. E., Arabadzhyan A., González M. M., and León C. J. (2022). Macroeconomic impacts of climate change on the Blue Economy sectors of southern European islands. *Climatic Change*, *170*(3–4), 27. doi: 10.1007/s10584-022-03310-5

Vuik V., Jonkman S. N., Borsje B. W., and Suzuki T. (2016). Nature-based flood protection: The efficiency of vegetated foreshores for reducing wave loads on coastal dikes. *Coastal Engineering*, *116*, 42–56. doi: 10.1016/j.coastaleng.2016.06.001

Wallentinus I., and Nyberg C. D. (2007). Introduced marine organisms as habitat modifiers. *Marine Pollution Bulletin*, *55*(7–9). doi: 10.1016/j.marpolbul.2006.11.010

Ward P. J., de Ruiter M. C., Mård J., Schröter K., Van Loon A., Veldkamp T., von Uexkull N., Wanders N., AghaKouchak A., Arnbjerg-Nielsen K., Capewell L., Carmen Llasat M., Day R., Dewals B., Di Baldassarre G., Huning L. S., Kreibich H., Mazzoleni M., Savelli E., … Wens M. (2020). The need to integrate flood and drought disaster risk reduction strategies. *Water Security*, *11*, 100070. doi: 10.1016/j.wasec.2020.100070

Watts N., Amann M., Arnell N., Ayeb-Karlsson S., Belesova K., Boykoff M., Byass P., Cai W., Campbell-Lendrum D., Capstick S., Chambers J., Dalin C., Daly M., Dasandi N., Davies M., Drummond P., Dubrow R., Ebi K. L., Eckelman M., … Montgomery H. (2019). The 2019 report of The Lancet Countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate. *The Lancet*, *394*(10211), 1836–1878. doi: 10.1016/s0140-6736(19)32596-6

Wedler M., Pinto J. G., and Hochman A. (2023). More frequent, persistent, and deadly heat waves in the 21st century over the Eastern Mediterranean. *Science of The Total Environment*, *870*, 161883. doi: 10.1016/j.scitotenv.2023.161883

WHO (2021). *WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. World Health Organization. https://iris.who.int/handle/10665/345334.

Wolff C., Nikoletopoulos T., Hinkel J., and Vafeidis A. T. (2020). Future urban development exacerbates coastal exposure in the Mediterranean. *Scientific Reports*, *10*(1), 14420. doi: 10.1038/s41598-020-70928-9

Wolff C., Vafeidis A. T., Muis S., Lincke D., Satta A., Lionello P., Jimenez J. A., Conte D., and Hinkel J. (2018). A Mediterranean coastal database for assessing the impacts of sea-level rise and associated hazards. *Scientific Data*, *5*(1), 180044. doi: 10.1038/sdata.2018.44

World Tourism Organization (2008). *Climate Change and Tourism – Responding to Global Challenges*. UNWTO, Madrid. doi: 10.18111/9789284412341

World Tourism Organization. (2018). UNWTO Tourism Highlights, 2018 Edition. In *UNWTO Tourism Highlights: 2018 Edition*. UNWTO, Madrid. doi: 10.18111/9789284419876

Yang L., Zhou Y., Shi B., Meng J., He B., Yang H., Yoon S. J., Kim T., Kwon B.-O., and Khim J. S. (2020). Anthropogenic impacts on the contamination of pharmaceuticals and personal care products (PPCPs) in the coastal environments of the Yellow and Bohai seas. *Environment International*, *135*, 105306. doi: 10.1016/j.envint.2019.105306

Yang X. (2008). ISPRS Journal of Photogrammetry and Remote Sensing theme issue "Remote Sensing of the Coastal Ecosystems." *ISPRS Journal of Photogrammetry and Remote Sensing*, *63*(5), 485–487. doi: 10.1016/j.isprsjprs.2008.07.001

Yavuz C., Kentel E., and Aral M. M. (2020). Climate Change Risk Evaluation of Tsunami Hazards in the Eastern Mediterranean Sea. *Water*, *12*(10), 2881. doi: 10.3390/w12102881

Yesudian A. N., and Dawson R. J. (2021). Global analysis of sea level rise risk to airports. *Climate Risk Management*, *31*, 100266. doi: 10.1016/j.crm.2020.100266

Yilmaz A. B., Yanar A., and Alkan E. (2017). Review of heavy metal accumulation on aquatic environment in Northern East Mediterrenean Sea part I: some essential metals. *Reviews on Environmental Health*, *32*(1–2), 119–163. doi: 10.1515/reveh-2016-0065

Yilmaz A. B., Yanar A., and Alkan E. (2018). Review of Heavy Metal Accumulation in Aquatic Environment of Northern East Mediterrenean Sea Part II: Some Non-Essential Metals. *Pollution*, *4*(1), 143–181. doi: 10.22059/poll.2017.236121.287

Zampieri M., Toreti A., Ceglar A., Naumann G., Turco M., and Tebaldi C. (2020). Climate resilience of the top ten wheat producers in the Mediterranean and the Middle East. *Regional Environmental Change*, *20*(2), 41. https://doi.org/10.1007/s10113-020-01622-9

Zebakh S., Abdelradi F., Mohamed E. Sh., Amawi O., Sadiki M., and Rhouma A. (2022). Chapter 15: Innovations on the nexus for development and growth in the south Mediterranean region. In *Handbook on the Water-Energy-Food Nexus* (pp. 273–290). Geography, Planning and Tourism 2022. doi: 10.4337/9781839100550.00022

Zeki S., Aslan A., Burak S., and Rose J. B. (2021). Occurrence of a human-associated microbial source tracking marker and its relationship with faecal indicator bacteria in an urban estuary. *Letters in Applied Microbiology*, *72*(2), 167–177. doi: 10.1111/lam.13405

Zouahri A., Dakak H., Douaik A., El Khadir M., and Moussadek R. (2015). Evaluation of groundwater suitability for irrigation in the Skhirat region, Northwest of Morocco. *Environmental Monitoring and Assessment*, *187*(1), 4184. doi: 10.1007/s10661-014-4184-9

Zscheischler J., Martius O., Westra S., Bevacqua E., Raymond C., Horton R. M., van den Hurk B., AghaKouchak A., Jézéquel A., Mahecha M. D., Maraun D., Ramos A. M., Ridder N. N., Thiery W., and Vignotto E. (2020). A typology of compound weather and climate events. *Nature Reviews Earth and Environment*, *1*(7), 333–347. doi: 10.1038/s43017-020-0060-z

Zviely D., Bitan M., and DiSegni D. M. (2015). The effect of sea-level rise in the 21st century on marine structures along the Mediterranean coast of Israel: An evaluation of physical damage and adaptation cost. *Applied Geography*, *57*, 154–162. doi: 10.1016/j.apgeog.2014.12.007

3

Information about the authors

Coordinating Lead Authors

Z. Selmin BURAK, Institute of Marine Sciences and Management, Istanbul University, *Istanbul, Türkiye*
Nathalie HILMI, Department of Environmental Economics, Centre Scientifique de Monaco, *Monaco*
José A. JIMÉNEZ, Laboratori d'Enginyeria Marítima, Universitat Politécnica de Catalunya·BarcelonaTech, *Barcelona, Spain*

Lead Authors

Elham ALI, Suez University / The National Authority for Remote Sensing & Space Sciences (NARSS), *Cairo, Egypt*
Mario V. BALZAN, Institute of Applied Sciences, *Malta* College of Arts, Science and Technology, *Paola, Malta*
Alessandra BONAZZA, National Research Council of Italy (CNR), Institute of Atmospheric Sciences and Climate, *Bologna, Italy*
Marie-Yasmine DECHRAOUI BOTTEIN, Université Côte d'Azur, CNRS, ECOSEAS, *Nice, France*
Nazli DEMIREL, Institute of Marine Sciences and Management, Istanbul University, *Istanbul, Türkiye*
Shekoofeh FARAHMAND, Department of Economics, University of Isfahan, *Isfahan, Iran*
Mauricio GONZÁLEZ, IHCantabria – Instituto de Hidráulica Ambiental de La Universidad de Cantabria, *Santander, Spain*
Sebastián MONTSERRAT, Department of Physics, University of the Balearic Islands (UIB), *Palma, Spain*
David PULIDO-VELAZQUEZ, Spanish Geological Survey (IGME-CSIC), *Granada, Spain*
Alain SAFA, Université Côte d'Azur, IAE, GRM, *Nice, France*
Matteo VACCHI, Department of Earth Sciences, University of Pisa, *Pisa, Italy*

Contributing Authors

Ignacio AGUIRRE AYERBE, IHCantabria – Instituto de Hidráulica Ambiental de La Universidad de Cantabria, *Santander, Spain*
Iñigo ANIEL-QUIROGA, IHCantabria – Instituto de Hidráulica Ambiental de La Universidad de Cantabria, *Santander, Spain*
Nuno CAIOLA, Department of Climate Solutions and Ecosystem Services, Eurecat, *Amposta, Spain*
Emma CALIKANZAROS, Université Côte d'Azur, CNRS, ECOSEAS, *Nice, France*
Dario CAMUFFO, National Research Council of Italy (CNR), Institute of Atmospheric Sciences and Climate, *Padua, Italy*
Mine CINAR, Department of Economics, Loyola University Chicago, *Chicago, USA*
María Carmen LLASAT, Department of Applied Physics, University of Barcelona, *Barcelona, Spain*
Alban THOMAS, Grenoble Applied Economics Laboratory (GAEL), University Grenoble-Alpes, INRAE, *Grenoble, France*

Managing climate and environmental risks

4

Coordinating Lead Authors:
Mohamed ABDRABO *(Egypt)*, **Athanasios T. VAFEIDIS** *(Germany/Greece)*

Lead Authors:
Gonéri Le COZANNET *(France)*, **Savvas GENITSARIS** *(Greece)*, **Michelle PORTMAN** *(Israel)*, **Daria POVH ŠKUGOR** *(Croatia)*

Contributing Authors:
Cécile CAPDERREY *(France)*, **Sinja DITTMANN** *(Germany)*, **Joachim GARRABOU** *(Spain)*, **Mauricio GONZÁLEZ** *(Spain)*, **Sebastián MONTSERRAT** *(Spain)*, **Marie PETTENATI** *(France)*, **Agustín SÁNCHEZ-ARCILLA** *(Spain)*

This document should be cited as:
Abdrabo, M., Vafeidis, A. T., Le Cozannet, G., Genitsaris, S., Portman, M., Povh Škugor, D., 2024: Managing Climatic and Environmental Risks. In: *Climate and Environmental Coastal Risks in the Mediterranean.* [Djoundourian, S., Lionello, P., Llasat, M.C., Guiot, J., Cramer, W., Driouech, F., Gattacceca, J.C., Marini, K. (eds.)]. MedECC Reports. MedECC Secretariat, Marseille, France, pp. 209-252, doi: 10.5281/zenodo.15096270

4

Chapter 4
Managing climate and environmental risks

Executive Summary

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

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

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

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

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

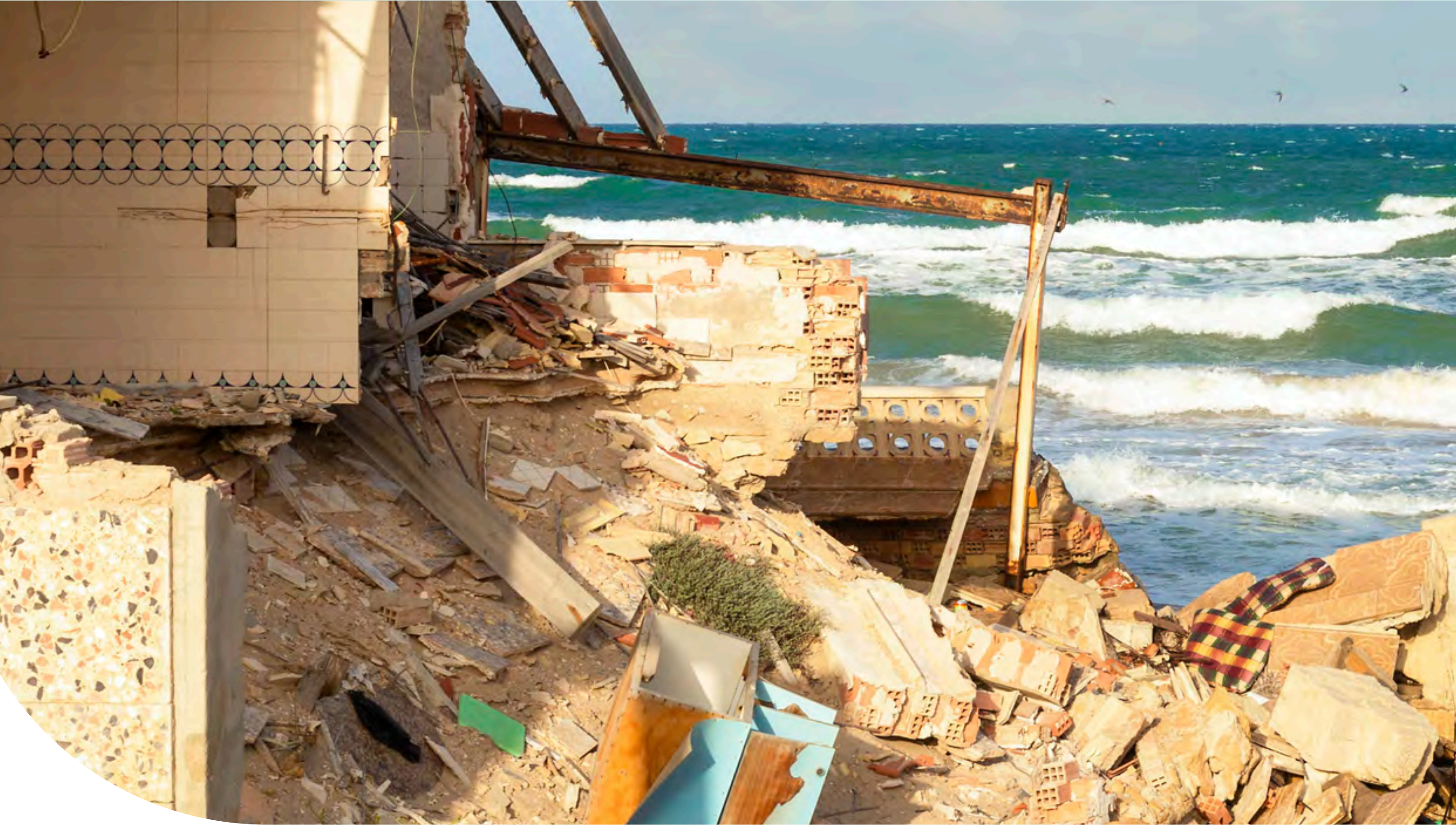
Mediterranean coastal ecosystems are those most threatened should regional climate change accelerate at a rapid rate due to human pressures and limited possibilities to migrate *(high confidence).* Many Mediterranean terrestrial, freshwater and marine coastal species and ecosystems are characterised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

***Reducing pollution* {4.3}**

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

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

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



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

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

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

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

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

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

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

4.1 Introduction

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

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

4.2. Adaptation to climate change

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

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

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

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

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

4.2.1 Coastal flooding

4.2.1.1 Protection

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

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

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

4.2.1.2 Accommodation

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

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

4.2.1.3 Relocation, avoidance, and advance

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

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

4.2.2 Coastal erosion and shoreline changes

4.2.2.1 Protection

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

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

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

4.2.2.2 Relocation

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

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

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

4.2.3 Loss of coastal ecosystems

4.2.3.1 Autonomous adaptation

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

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

4.2.3.2 Measures supporting autonomous adaptation

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

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

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

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

4.2.3.3 Technologies and innovation

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

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

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

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

4.2.3.4 Socio-institutional adaptation

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

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

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

4.2.4 Scarcity of coastal freshwater resources

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

4.2.4.1 Increasing water supply

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

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

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

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

4.2.4.2 Demand-oriented adaptation

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

4.2.4.3 Improving water quality

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

4.2.4.4 Governance

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

4.2.5 Acidification of coastal waters

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

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

4.3 Pollution management and solutions

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

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

4.3.1 Municipal waste

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

4.3.2 Wastewater

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

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

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

4.3.3 Waste discharge

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

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

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

---

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

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

[48] https://www.greenkey.global/

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

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

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

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

4.3.4 Plastic litter

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

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

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

4.3.5 Metals, persistent organic pollutants, and emerging pollutants

4.3.5.1 Metals

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

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

---

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

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

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

4.3.5.2 Persistent organic pollutants and emerging pollutants

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

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

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

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

4.3.6 Source point versus end point solutions

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

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

For example, for the restoration of seven coastal lagoons in southern France, plans included attempts to restore seagrass meadows by actively planting or seeding and subsequently harvesting their biomass, which stores excessive nutrients. Macroalgal growth can accelerate the decrease of total N and P contents, provided that its biomass is exported from the lagoon (De Wit et al. 2017). Overall, macrophyte and angiosperm transplants in coastal sites are a frequent and effective strategy to reduce external nutrient loading. Over four years of plant transplantations at 32 stations in the Venice Lagoon, extensive meadows were formed over a surface area of approximately 10 km² and a rapid recovery of the ecological status of the relevant areas was observed (Sfriso et al. 2021). Similarly, wetland plants promote soil metal adsorption through soil oxygenation. The angiosperm *Paspalum distichum* was found to be a potential phytoremediator of water metal pollution in mesocosm-field experiments in a newly established restored marsh in the Ebro Delta (Spain), highlighting the utility of restored marshes as metal filters in coastal Mediterranean systems. However, this bottom-up approach to nutrient-metal loading management often does not match with community recovery, and restoration is therefore *likely* not apparent (Duarte et al. 2009). Top-down approaches that target the eutrophication results, that is the development of Harmful Algal Blooms (HABs), have thus been examined in theory with the proposal to test filter-feeder species farming being qualified (Petersen et al. 2014). However, these have yet to be applied on large scales in the Mediterranean region due to associated bottlenecks of shellfish farming which impair the beneficial effects on nutrient harvesting (Stadmark and Conley 2011).

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

4.4 Non-indigenous species

4.4.1 Challenges

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

4.4.2 Solutions

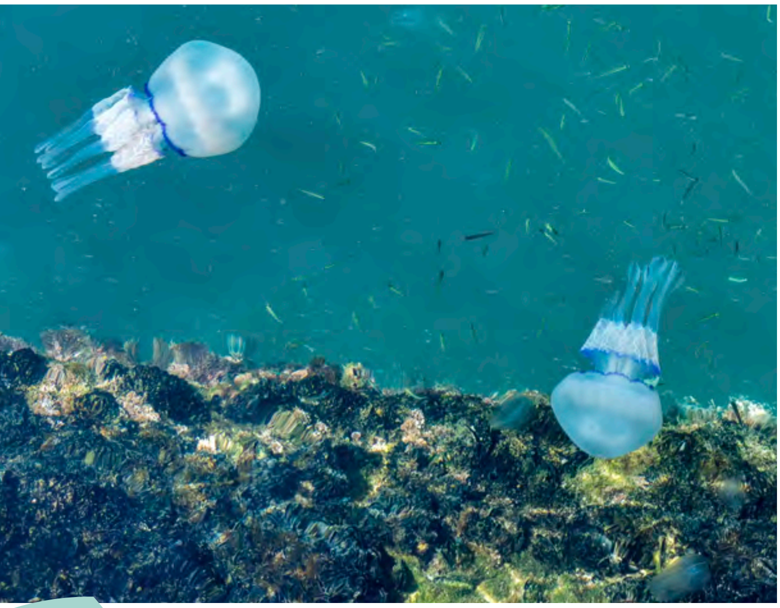
While such problems are observed throughout the Mediterranean region, few solutions have advanced and only in a few locations. In general, controlling non-indigenous species in marine environments faces considerable challenges compared to terrestrial environments (Giakoumi et al. 2019). Some of the most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

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

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

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

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



4.5 Risk synergies and management considerations

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

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

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

4.5.1 Managing the risks of consecutive events

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

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

Tsunamis

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

---

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

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

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

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

4.5.2 Residual risks

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

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

---

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

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

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

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

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

4.6 Barriers to effective responses

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

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

4.7 Science-policy interface

4.7.1 Defining science needed for policymaking in times of climate emergency

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

---

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

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

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

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

Box 4.1

Examples of science policy collaboration in the Mediterranean

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

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

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

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

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

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

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

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

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

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

---

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

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

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

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

4.8 Final remarks

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

References

Abdrabo M. A., and Hassaan M. A. (2020). Assessment of Policy-Research Interaction on Climate Change Adaptation Action: Inundation by Sea Level Rise in the Nile Delta. *Journal of Geoscience and Environment Protection, 08*(10), 314–329. doi: 10.4236/gep.2020.810020

Abi Saab M. T., Daou C., Bashour I., Maacaron A., Fahed S., Romanos D., Khairallah Y., Lebbous N., Hajjar C., Saad R. A., Ojeil C., Sellami M. H., Roukoz S., and Salman M. (2021). Treated municipal wastewater reuse for eggplant irrigation. *Australian Journal of Crop Science, 15*(8), 1095–1101. doi: 10.21475/ajcs.21.15.08.p2711

Abi Saab M. T., Zaghrini J., Makhlouf H., Fahed S., Romanos D., Khairallah Y., Hajjar C., Abi Saad R., Sellami M. H., and Todorovic M. (2021). Table grapes irrigation with treated municipal wastewater in a Mediterranean environment. *Water and Environment Journal, 35*(2), 617–627. doi: 10.1111/wej.12656

Agamuthu P., Mehran S. B., Norkhairah A., and Norkhairiyah A. (2019). Marine debris: A review of impacts and global initiatives. *Waste Management and Research, 37*(10), 987–1002. doi: 10.1177/0734242x19845041

Ahrens L., Shoeib M., Harner T., Lee S. C., Guo R., and Reiner E. J. (2011). Wastewater Treatment Plant and Landfills as Sources of Polyfluoroalkyl Compounds to the Atmosphere. *Environmental Science & Technology, 45*(19), 8098–8105. doi: 10.1021/es1036173

Airoldi L., and Bulleri F. (2011). Anthropogenic Disturbance Can Determine the Magnitude of Opportunistic Species Responses on Marine Urban Infrastructures. *PLOS ONE, 6*(8), e22985. doi: 10.1371/journal.pone.0022985

Alayande A. B., Lim J., Kim J., Hong S., Al-Amoudi A. S., and Park B. (2022). Fouling control in SWRO desalination during harmful algal blooms: A historical review and future developments. *Desalination, 543, 116094.* doi: 10.1016/j.desal.2022.116094

Ali E., Cramer W., Carnicer J., Georgopoulou E., Hilmi N. J. M., Le Cozannet G., and Lionello P. (2022). Cross-Chapter Paper 4: Mediterranean Region. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2233–2272. doi:10.1017/9781009325844.021

Álvarez-Manzaneda I., Guerrero F., Cruz-Pizarro L., Rendón M., and De Vicente I. (2021). Magnetic particles as new adsorbents for the reduction of phosphate inputs from a wastewater treatment plant to a Mediterranean Ramsar wetland (Southern Spain). *Chemosphere, 270,* 128640. doi: 10.1016/j.chemosph ere.2020.128640

Álvarez-Rogel J., Barberá G. G., Maxwell B., Guerrero-Brotons M., Díaz-García C., Martínez-Sánchez J. J., Sallent A., Martínez-Ródenas J., González-Alcaraz M. N., Jiménez-Cárceles F. J., Tercero C., and Gómez R. (2020). The case of Mar Menor eutrophication: State of the art and description of tested Nature-Based Solutions. *Ecological Engineering, 158,* 106086. doi: 10.1016/j.ecoleng.2020.106086

André C., Boulet D., Rey-Valette H., and Rulleau B. (2016). Protection by hard defence structures or relocation of assets exposed to coastal risks: Contributions and drawbacks of cost-benefit analysis for long-term adaptation choices to climate change. *Ocean & Coastal Management*, *134*, 173–182. doi: 10.1016/j.ocecoaman.2016.10.003

Asensio-Montesinos F., Pranzini E., Martínez-Martínez J., Cinelli I., Anfuso G., and Corbí H. (2020). The Origin of Sand and Its Colour on the South-Eastern Coast of Spain: Implications for Erosion Management. *Water, 12*(2), 377. doi: 10.3390/w12020377

Aurelle D., Thomas S., Albert C., Bally M., Bondeau A., Boudouresque C., Cahill A. E., Carlotti F., Chenuil A., Cramer W., Davi H., De Jode A., Ereskovsky A., Farnet A., Fernandez C., Gauquelin T., Mirleau P., Monnet A., Prévosto B., … Fady B. (2022). Biodiversity, climate change, and adaptation in the Mediterranean. *Ecosphere, 13*(4). doi: 10.1002/ecs2.3915

Azzurro E., Sbragaglia V., Cerri J., Bariche M., Bolognini L., Ben Souissi J., Busoni G., Coco S., Chryssanthi A., Fanelli E., Ghanem R., Garrabou J., Gianni F., Grati F., Kolitari J., Letterio G., Lipej L., Mazzoldi C., Milone N., … Moschella P. (2019). Climate change, biological invasions, and the shifting distribution of Mediterranean fishes: A large-scale survey based on local ecological knowledge. *Global Change Biology, 25*(8), 2779–2792. doi: 10.1111/gcb.14670

Barón E., Giménez J., Verborgh P., Gauffier P., De Stephanis R., Eljarrat E., and Barceló D. (2015). Bioaccumulation and biomagnification of classical flame retardants, related halogenated natural compounds and alternative flame retardants in three delphinids from Southern European waters. *Environmental Pollution, 203,* 107–115. doi: 10.1016/j.envpol.2015.03.041

Barón E., Máñez M., Andreu A. C., Sergio F., Hiraldo F., Eljarrat E., and Barceló D. (2014). Bioaccumulation and biomagnification of emerging and classical flame retardants in bird eggs of 14 species from Doñana Natural Space and surrounding areas (South-western Spain). *Environment International, 68,* 118–126. doi: 10.1016/j.envint.2014.03.013

Beca-Carretero P., Winters G., Teichberg M., Procaccini G., Schneekloth F., Zambrano R. H., Chiquillo K., and Reuter H. (2024). Climate change and the presence of invasive species will threaten the persistence of the Mediterranean seagrass community. *Science of The Total Environment, 910,* 168675. doi: 10.1016/j.scitotenv.2023.168675

Bednar-Friedl B., Biesbroek R., Schmidt D. N., Alexander P., Børsheim K. Y., Carnicer J., Georgopoulou E., Haasnoot M., Cozannet G. Le, Lionello P., Lipka O., Möllmann C., Muccione V., Mustonen T., Piepenburg D., and Whitmarsh L. (2022). Europe. In H. O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (p. 1927).* Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1817-1927. doi: 10.1017/9781009325844.015

Benedicto J., Martínez-Gómez C., Guerrero J., Jornet A., and Rodríguez C. (2008). Metal contamination in Portman Bay (Murcia, SE Spain) 15 years after the cessation of mining activities. *Ciencias Marinas, 34*(3). doi: 10.7773/cm.v34i3.1391

Bevacqua E., Maraun D., Vousdoukas M. I., Voukouvalas E., Vrac M., Mentaschi L., and Widmann M. (2019). Higher probability of compound flooding from precipitation and storm surge in Europe under anthropogenic climate change. *Science Advances, 5*(9), eaaw5531. doi: 10.1126/sciadv.aaw5531

Bindoff N. L., Cheung W. W. L., Kairo J. G., Arístegui J., Guinder V. A., Hallberg R., Hilmi N., Jiao N., Karim M. S., Levin L., O'Donoghue S., Purca Cuicapusa S. R., Rinkevich B., Suga T., Tagliabue A., and Williamson P. (2022). Changing Ocean, Marine Ecosystems, and Dependent Communities. In H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N. M. Weyer (Eds.), *The Ocean and Cryosphere in a Changing Climate* (pp. 447–588). Cambridge University Press. doi: 10.1017/9781009157964.007

Biondo M., Buosi C., Trogu D., Mansfield H., Vacchi M., Ibba A., Porta M., Ruju A., and De Muro S. (2020). Natural vs. Anthropic Influence on the Multidecadal Shoreline Changes of Mediterranean Urban Beaches: Lessons from the Gulf of Cagliari (Sardinia). *Water, 12*(12), 3578. doi: 10.3390/w12123578

Bitan M., and Zviely D. (2020). Sand Beach Nourishment: Experience from the Mediterranean Coast of Israel. *Journal of Marine Science and Engineering, 8*(4), 273. doi: 10.3390/jmse8040273

Blanchet J., and Creutin J. (2017). Co-Occurrence of Extreme Daily Rainfall in the French Mediterranean Region. *Water Resources Research, 53*(11), 9330–9349. doi: 10.1002/2017wr020717

Brouziyne Y., Abouabdillah A., Hirich A., Bouabid R., Zaaboul R., and Benaabidate L. (2018). Modeling sustainable adaptation strategies toward a climate-smart agriculture in a Mediterranean watershed under projected climate change scenarios. *Agricultural Systems, 162,* 154–163. doi:10.1016/j.agsy.2018.01.024

Bruni C., Akyol Ç., Cipolletta G., Eusebi A. L., Caniani D., Masi S., Colón J., and Fatone F. (2020). Decentralized Community Composting: Past, Present and Future Aspects of Italy. *Sustainability, 12*(8), 3319. doi: 10.3390/su12083319

Butenschön M., Lovato T., Masina S., Caserini S., and Grosso M. (2021). Alkalinization Scenarios in the Mediterranean Sea for Efficient Removal of Atmospheric CO2 and the Mitigation of Ocean Acidification. *Frontiers in Climate, 3,* 614537. doi: 10.3389/fclim.2021.614537

Campo J., Masiá A., Picó Y., Farré M., and Barceló D. (2014). Distribution and fate of perfluoroalkyl substances in Mediterranean Spanish sewage treatment plants. *Science of The Total Environment, 472,* 912–922. doi: 10.1016/j.scitotenv.2013.11.056

Cantasano N. (2022). Marine Pollution by Microplastics in the Mediterranean Sea. *Journal of Marine Science and Engineering, 10*(7), 858. doi: 10.3390/jmse10070858

Capó X., Tejada S., Ferriol P., Pinya S., Mateu-Vicens G., Montero-González I., Box A., and Sureda A. (2020). Hypersaline water from desalinization plants causes oxidative damage in Posidonia oceanica meadows. *Science of The Total Environment, 736,* 139601. doi: 10.1016/j.scitotenv.2020.139601

Caretta A. M., Mukherji A., Arfanuzzaman M., Betts R. A., Gelfan A., Hirabayashi Y., Lissner T. K., Gunn E. L., Liu J., Morgan R., Mwanga S., Supratid S., and Kumar M. (2022). Water. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 551-712. doi: 10.1017/9781009325844.006

Castro-Jiménez J., Bănaru D., Chen C.-T., Jiménez B., Muñoz-Arnanz J., Deviller G., and Sempéré R. (2021). Persistent Organic Pollutants Burden, Trophic Magnification and Risk in a Pelagic Food Web from Coastal NW Mediterranean Sea. *Environmental Science & Technology, 55*(14), 9557–9568. doi: 10.1021/acs.est.1c00904

Cebrian E., Tamburello L., Verdura J., Guarnieri G., Medrano A., Linares C., Hereu B., Garrabou J., Cerrano C., Galobart C., and Fraschetti S. (2021). A Roadmap for the Restoration of Mediterranean Macroalgal Forests. *Frontiers in Marine Science, 8,* 709219. doi: 10.3389/fmars.2021.709219

Choi B. C. K., Pang T., Lin V., Puska P., Sherman G., Goddard M., Ackland M. J., Sainsbury P., Stachenko S., Morrison H., and Clottey C. (2005). Can scientists and policy makers work together? *Journal of Epidemiology & Community Health, 59*(8), 632–637. doi: 10.1136/jech.2004.031765

Christie P. (2011). Creating space for interdisciplinary marine and coastal research: five dilemmas and suggested resolutions. *Environmental Conservation, 38*(2), 172–186. doi: 10.1017/S0376892911000129

Ciampa F., Seifollahi-Aghmiuni S., Kalantari Z., and Ferreira C. S. S. (2021). Flood Mitigation in Mediterranean Coastal Regions: Problems, Solutions, and Stakeholder Involvement. *Sustainability, 13*(18), 10474. doi: 10.3390/su131810474

Clément V., Rey-Valette H., and Rulleau B. (2015). Perceptions on equity and responsibility in coastal zone policies. *Ecological Economics, 119,* 284–291. doi: 10.1016/j.ecolecon.2015.09.005

Council Directive 91/676/EEC. (2000). *Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. Official Journal, L 375,* 1-8. http://data.europa.eu/eli/dir/1991/676/oj

Cózar A., Sanz-Martín M., Martí E., González-Gordillo J. I., Ubeda B., Gálvez J. Á., Irigoien X., and Duarte C. M. (2015). Plastic Accumulation in the Mediterranean Sea. *PLOS ONE, 10*(4), e0121762. doi: 10.1371/journal.pone.0121762

Cozar Cabañas A., Sanz-Martín M., Martí E., Ignacio González-Gordillo J., Ubeda B., Gálvez J. Á., Irigoien X., and Duarte C. M. (2015). Concentrations of floating plastic debris in the Mediterranean Sea measured during MedSeA-2013 cruise [dataset]. *PANGAEA.* doi: 10.1594/PANGAEA.842054

Crémona C., Jeusset M., Vallée C., and Zouhny B. (2019). Durability analysis of the maritime infrastructure for the Monaco Sea extension. *Structural Concrete, 20*(6), 2272–2285. doi: 10.1002/suco.201900120

Cristale J., Hurtado A., Gómez-Canela C., and Lacorte S. (2016). Occurrence and sources of brominated and organophosphorus flame retardants in dust from different indoor environments in Barcelona, Spain. *Environmental Research, 149,* 66–76. doi: 10.1016/j.envres.2016.05.001

Dachary-Bernard J., Rey-Valette H., and Rulleau et B. (2019). Preferences among coastal and inland residents relating to managed retreat: Influence of risk perception in acceptability of relocation strategies. *Journal of Environmental Management, 232,* 772–780. doi: 10.1016/j.jenvman.2018.11.104

Dafforn K. A., Mayer-Pinto M., Morris R. L., and Waltham N. J. (2015). Application of management tools to integrate ecological principles with the design of marine infrastructure. *Journal of Environmental Management, 158,* 61–73. doi: 10.1016/j.jenvman.2015.05.001

Danovaro R., Nepote E., Martire M. Lo, Ciotti C., De Grandis G., Corinaldesi C., Carugati L., Cerrano C., Pica D., Di Camillo C. G., and Dell'Anno A. (2018). Limited impact of beach nourishment on macrofaunal recruitment/settlement in a site of community interest in coastal area of the Adriatic Sea (Mediterranean Sea). *Marine Pollution Bulletin, 128,* 259–266. doi: 10.1016/j.marpolbul.2018.01.033

de Ruiter M. C., Couasnon A., van den Homberg M. J. C., Daniell J. E., Gill J. C., and Ward P. J. (2020). Why We Can No Longer Ignore Consecutive Disasters. *Earth's Future, 8*(3). doi: 10.1029/2019ef001425

de Schipper M. A., Ludka B. C., Raubenheimer B., Luijendijk A. P., and Schlacher Thomas. A. (2020). Beach nourishment has complex implications for the future of sandy shores. *Nature Reviews Earth & Environment, 2*(1), 70–84. doi: 10.1038/s43017-020-00109-9

de Sosa L., Benítez E., Girón I., and Madejón E. (2021). Agro-Industrial and Urban Compost as an Alternative of Inorganic Fertilizers in Traditional Rainfed Olive Grove under Mediterranean Conditions. *Agronomy, 11*(6), 1223. doi: 10.3390/agronomy11061223

De Vivo C., Ellena M., Capozzi V., Budillon G., and Mercogliano P. (2022). Risk assessment framework for Mediterranean airports: a focus on extreme temperatures and precipitations and sea level rise. *Natural Hazards, 111*(1), 547–566. doi: /10.1007/s11069-021-05066-0

De Wit R., Rey-Valette H., Balavoine J., Ouisse V., and Lifran R. (2017). Restoration ecology of coastal lagoons: new methods for the prediction of ecological trajectories and economic valuation. *Aquatic Conservation: Marine and Freshwater Ecosystems, 27*(1), 137–157. doi: 10.1002/aqc.2601

de-los-Ríos-Mérida J., Guerrero F., Arijo S., Muñoz M., Álvarez-Manzaneda I., García-Márquez J., Bautista B., Rendón-Martos M., and Reul A. (2021). Wastewater Discharge through a Stream into a Mediterranean Ramsar Wetland: Evaluation and Proposal of a Nature-Based Treatment System. *Sustainability, 13*(6), 3540. doi: 10.3390/su13063540

Diamantis V., Erguder T. H., Aivasidis A., Verstraete W., and Voudrias E. (2013). Wastewater disposal to landfill-sites: A synergistic solution for centralized management of olive mill wastewater and enhanced production of landfill gas. *Journal of Environmental Management, 128,* 427–434. doi: 10.1016/j.jenvman.2013.05.051

Dillon P., Fernández Escalante E., Megdal S. B., and Massmann G. (2020). Managed Aquifer Recharge for Water Resilience. *Water, 12*(7), 1846. doi: 10.3390/w12071846

Directive 2000/60/E (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. *Official Journal,* L 327, 1-73. http://data.europa.eu/eli/dir/2000/60/oj

Directive 2008/56/EC (2008). Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (Text with EEA relevance). *Official Journal,* L 164, 19-40. http://data.europa.eu/eli/dir/2008/56/oj

Directive (EU) 2019/904 (2019). Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment (Text with EEA relevance). *Official Journal,* L 155, 1-19. http://data.europa.eu/eli/dir/2019/904/oj

Domingues E., Gomes J., Quina M., Quinta-Ferreira R., and Martins R. (2018). Detoxification of Olive Mill Wastewaters by Fenton's Process. *Catalysts, 8*(12), 662. doi: 10.3390/catal8120662

Drius M., Bongiorni L., Depellegrin D., Menegon S., Pugnetti A., and Stifter S. (2019). Tackling challenges for Mediterranean sustainable coastal tourism: An ecosystem service perspective. *Science of The Total Environment, 652,* 1302–1317. doi: 10.1016/j.scitotenv.2018.10.121

Duarte C. M., Conley D. J., Carstensen J., and Sánchez-Camacho M. (2009). Return to Neverland: Shifting Baselines Affect Eutrophication Restoration Targets. *Estuaries and Coasts, 32*(1), 29–36. doi: 10.1007/s12237-008-9111-2

Durand P., Anselme B., Defossez S., Elineau S., Gherardi M., Goeldner-Gianella L., Longépée E., and Nicolae-Lerma A. (2018). Coastal flood risk: improving operational response, a case study on the municipality of Leucate, Languedoc, France. *Geoenvironmental Disasters, 5*(1), 19. doi: 10.1186/s40677-018-0109-1

EC (2010). Marine Strategy Framework Directive – Task group 5 Report – Eutrophication, April 2010 (N. Zampoukas, Ed.). *Publications Office.* doi: 10.2788/86830

EC Secretariat-General (2019). *European Green Deal. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions — The European Green Deal (COM(2019) 640 final, 11.12.2019).* doi: 10.2775/373022

El-Masry E. A. (2022). Beach responses to coastal structures and their impacts on tourism investment, Sidi Abd El-Rahman coastal zone – Mediterranean Sea, Egypt. *Arabian Journal of Geosciences, 15*(23), 1708. doi: 10.1007/s12517-022-11008-2

El-Masry E. A., El-Sayed M. Kh., Awad M. A., El-Sammak A. A., and Sabarouti M. A. El. (2022). Vulnerability of tourism to climate change on the Mediterranean coastal area of El Hammam–EL Alamein, Egypt. *Environment, Development and Sustainability, 24*(1), 1145–1165. doi: 10.1007/s10668-021-01488-9

El-Mezayen M. M., Rueda-Roa D. T., Essa M. A., Muller-Karger F. E., and Elghobashy A. E. (2018). Water quality observations in the marine aquaculture complex of the Deeba Triangle, Lake Manzala, Egyptian Mediterranean coast. *Environmental Monitoring and Assessment, 190*(7), 436. doi: 10.1007/s10661-018-6800-6

Erostate M., Huneau F., Garel E., Ghiotti S., Vystavna Y., Garrido M., and Pasqualini V. (2020). Groundwater dependent ecosystems in coastal Mediterranean regions: Characterization, challenges and management for their protection. *Water Research, 172,* 115461. doi: 10.1016/j.watres.2019.115461

Faraco V., and Hadar Y. (2011). The potential of lignocellulosic ethanol production in the Mediterranean Basin. *Renewable and Sustainable Energy Reviews, 15*(1), 252–266. doi: 10.1016/j.rser.2010.09.050

Fiori A., Mancini C. P., Annis A., Lollai S., Volpi E., Nardi F., and Grimaldi S. (2023). The role of residual risk on flood damage assessment: A continuous hydrologic-hydraulic modelling approach for the historical city of Rome, Italy. *Journal of Hydrology: Regional Studies, 49,* 101506. doi: 10.1016/j.ejrh.2023.101506

Fischione P., Pasquali D., Celli D., Di Nucci C., and Di Risio M. (2022). Beach Drainage System: A Comprehensive Review of a Controversial Soft-Engineering Method. *Journal of Marine Science and Engineering, 10*(2), 145. doi: 10.3390/jmse10020145

Fortibuoni T., Amadesi B., and Vlachogianni T. (2021). Composition and abundance of macrolitter along the Italian coastline: The first baseline assessment within the european Marine Strategy Framework Directive. *Environmental Pollution*, *268*, 115886. doi: 10.1016/j.envpol.2020.115886

Fossi M. C., and Panti C. (2020). The Impact of Marine Litter in Marine Protected Areas (MPAs) in the Mediterranean Sea: How Can We Protect MPAs? In M. Streit-Bianchi, M. Cimadevila, & W. Trettnak (Eds.), *Mare Plasticum - The Plastic Sea* (pp. 117–128). Springer, Cham. doi: 10.1007/978-3-030-38945-1_6

Fossi M. C., Vlachogianni T., Galgani F., Innocenti F. D., Zampetti G., and Leone G. (2020). Assessing and mitigating the harmful effects of plastic pollution: the collective multi-stakeholder driven Euro-Mediterranean response. *Ocean & Coastal Management, 184,* 105005. doi: 10.1016/j.ocecoaman.2019.105005

Fourqurean J. W., Duarte C. M., Kennedy H., Marbà N., Holmer M., Mateo M. A., Apostolaki E. T., Kendrick G. A., Krause-Jensen D., McGlathery K. J., and Serrano O. (2012). Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience, 5*(7), 505–509. doi: 10.1038/ngeo1477

Frascari D., Zanaroli G., Motaleb M. A., Annen G., Belguith K., Borin S., Choukr-Allah R., Gibert C., Jaouani A., Kalogerakis N., Karajeh F., Ker Rault P. A., Khadra R., Kyriacou S., Li W.-T., Molle B., Mulder M., Oertlé E., and Ortega C. V. (2018). Integrated technological and management solutions for wastewater treatment and efficient agricultural reuse in Egypt, Morocco, and Tunisia. *Integrated Environmental Assessment and Management, 14*(4), 447–462. doi: 10.1002/ieam.4045

Fytianos G., Ioannidou E., Thysiadou A., Mitropoulos A. C., and Kyzas G. Z. (2021). Microplastics in Mediterranean Coastal Countries: A Recent Overview. *Journal of Marine Science and Engineering, 9*(1), 98. doi: 10.3390/jmse9010098

Garrabou J., Gómez-Gras D., Ledoux J.-B., Linares C., Bensoussan N., López-Sendino P., Bazairi H., Espinosa F., Ramdani M., Grimes S., Benabdi M., Souissi J. Ben, Soufi E., Khamassi F., Ghanem R., Ocaña O., Ramos-Esplà A., Izquierdo A., Anton I., … Harmelin J. G. (2019). Collaborative Database to Track Mass Mortality Events in the Mediterranean Sea. *Frontiers in Marine Science, 6,* 707. doi: 10.3389/fmars.2019.00707

Garrabou J., Gómez-Gras D., Medrano A., Cerrano C., Ponti M., Schlegel R., Bensoussan N., Turicchia E., Sini M., Gerovasileiou V., Teixido N., Mirasole A., Tamburello L., Cebrian E., Rilov G., Ledoux J., Souissi J. Ben, Khamassi F., Ghanem R., … Harmelin J. (2022). Marine heatwaves drive recurrent mass mortalities in the Mediterranean Sea. *Global Change Biology, 28*(19), 5708–5725. doi: 10.1111/gcb.16301

Geijzendorffer I. R., Beltrame C., Chazee L., Gaget E., Galewski T., Guelmami A., Perennou C., Popoff N., Guerra C. A., Leberger R., Jalbert J., and Grillas P. (2019). A More Effective Ramsar Convention for the Conservation of Mediterranean Wetlands. *Frontiers in Ecology and Evolution, 7,* 21. doi: 10.3389/fevo.2019.00021

Giakoumi S., Katsanevakis S., Albano P. G., Azzurro E., Cardoso A. C., Cebrian E., Deidun A., Edelist D., Francour P., Jimenez C., Mačić V., Occhipinti-Ambrogi A., Rilov G., and Sghaier Y. R. (2019). Management priorities for marine invasive species. *Science of The Total Environment, 688,* 976–982. doi: 10.1016/j.scitotenv.2019.06.282

Giangrande A., Pierri C., Del Pasqua M., Gravili C., Gambi M. C., and Gravina M. F. (2020). The Mediterranean in check: Biological invasions in a changing sea. *Marine Ecology, 41*(2). doi: 10.1111/maec.12583

Giovos I., Kleitou P., Poursanidis D., Batjakas I., Bernardi G., Crocetta F., Doumpas N., Kalogirou S., Kampouris T. E., Keramidas I., Langeneck J., Maximiadi M., Mitsou E., Stoilas V.-O., Tiralongo F., Romanidis-Kyriakidis G., Xentidis N.-J., Zenetos A., and Katsanevakis S. (2019). Citizen-science for monitoring marine invasions and stimulating public engagement: a case project from the eastern Mediterranean. *Biological Invasions, 21*(12), 3707–3721. doi: 10.1007/s10530-019-02083-w

Gorjanc S., Klančnik K., Murillas-Maza A., Uyarra M. C., Papadopoulou N. K., Paramana Th., Smith C., Chalkiadaki O., Dassenakis M., and Peterlin M. (2020). Coordination of pollution-related MSFD measures in the Mediterranean - Where we stand now and insights for the future. *Marine Pollution Bulletin, 159,* 111476. doi: 10.1016/j.marpolbul.2020.111476

Green S. J., Dulvy N. K., Brooks A. M. L., Akins J. L., Cooper A. B., Miller S., and Côté I. M. (2014). Linking removal targets to the ecological effects of invaders: a predictive model and field test. *Ecological Applications, 24*(6), 1311–1322. doi: 10.1890/13-0979.1

Grizzetti B., Vigiak O., Udias A., Aloe A., Zanni M., Bouraoui F., Pistocchi A., Dorati C., Friedland R., De Roo A., Benitez Sanz C., Leip A., and Bielza M. (2021). How EU policies could reduce nutrient pollution in European inland and coastal waters. *Global Environmental Change, 69,* 102281. doi: 10.1016/j.gloenvcha.2021.102281

Gual Soler M., and Perez-Porro A. (2021). *Science and Innovation Diplomacy in the Mediterranean. Union for the Mediterranean, Barcelona.* https://ufmsecretariat.org/wp-content/uploads/2021/12/Report_Science_Innovation_Diplomacy_Mediterranean_ALTA.pdf

Guittonny-Philippe A., Masotti V., Höhener P., Boudenne J.-L., Viglione J., and Laffont-Schwob I. (2014). Constructed wetlands to reduce metal pollution from industrial catchments in aquatic Mediterranean ecosystems: A review to overcome obstacles and suggest potential solutions. *Environment International, 64,* 1–16. doi: 10.1016/j.envint.2013.11.016

Haasnoot M., Kwakkel J. H., Walker W. E., and Ter Maat J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change, 23*(2), 485–498. doi: 10.1016/j.gloenvcha.2012.12.006

Harmanny K. S., and Malek Ž. (2019). Adaptations in irrigated agriculture in the Mediterranean region: an overview and spatial analysis of implemented strategies. *Regional Environmental Change, 19*(5), 1401–1416. doi: 10.1007/s10113-019-01494-8

Hassoun A. E. R., Bantelman A., Canu D., Comeau S., Galdies C., Gattuso J.-P., Giani M., Grelaud M., Hendriks I. E., Ibello V., Idrissi M., Krasakopoulou E., Shaltout N., Solidoro C., Swarzenski P. W., and Ziveri P. (2022). Ocean acidification research in the Mediterranean Sea: Status, trends and next steps. *Frontiers in Marine Science, 9.* doi: 10.3389/fmars.2022.892670

Herbert-Read J. E., Thornton A., Amon D. J., Birchenough S. N. R., Côté I. M., Dias M. P., Godley B. J., Keith S. A., McKinley E., Peck L. S., Calado R., Defeo O., Degraer S., Johnston E. L., Kaartokallio H., Macreadie P. I., Metaxas A., Muthumbi A. W. N., Obura D. O., … Sutherland W. J. (2022). A global horizon scan of issues impacting marine and coastal biodiversity conservation. *Nature Ecology & Evolution, 6*(9), 1262–1270. doi: 10.1038/s41559-022-01812-0

Heurtefeux H., Sauboua P., Lanzellotti P., and Bichot A. (2011). Coastal Risk Management Modes: The Managed Realignment as a Risk Conception More Integrated. In M. Savino (Ed.), *Risk Management in Environment, Production and Economy.* InTechOpen. doi: 10.5772/16804

Hinkel J., Aerts J. C. J. H., Brown S., Jiménez J. A., Lincke D., Nicholls R. J., Scussolini P., Sanchez-Arcilla A., Vafeidis A., and Addo K. A. (2018). The ability of societies to adapt to twenty-first-century sea-level rise. *Nature Climate Change, 8*(7), 570–578. doi: 10.1038/s41558-018-0176-z

Hinkel J., Nicholls R. J., Vafeidis A. T., Tol R. S. J., and Avagianou T. (2010). Assessing risk of and adaptation to sea-level rise in the European Union: an application of DIVA. *Mitigation and Adaptation Strategies for Global Change, 15*(7), 703–719. doi: 10.1007/s11027-010-9237-y

Howarth C., Parsons L., and Thew H. (2020). Effectively Communicating Climate Science beyond Academia: Harnessing the Heterogeneity of Climate Knowledge. *One Earth, 2*(4), 320–324. doi: 10.1016/j.oneear.2020.04.001

Iamiceli A., Ubaldi A., Lucchetti D., Brambilla G., Abate V., De Felip E., De Filippis S. P., Dellatte E., De Luca S., Ferri F., Fochi I., Fulgenzi A., Iacovella N., Moret I., Piazza R., Roncarati A., Melotti P., Fanelli R., Fattore E., … Miniero R. (2015). Metals in Mediterranean aquatic species. *Marine Pollution Bulletin, 94*(1–2), 278–283. doi: 10.1016/j.marpolbul.2015.02.034

Ibidhi R., and Calsamiglia S. (2020). Carbon Footprint Assessment of Spanish Dairy Cattle Farms: Effectiveness of Dietary and Farm Management Practices as a Mitigation Strategy. *Animals (Basel), 10*(11), 1–15. doi: 10.3390/ani10112083

IOC (2007). *Tsunami Early Warning and Mitigation System in the North Eastern Atlantic, the Mediterranean and Connected Seas, NEAMTWS: implementation plan.* UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000384929

IPBES (2018a). *Summary for policymakers of the assessment report on land degradation and restoration of the Intergovernmental SciencePolicy Platform on Biodiversity and Ecosystem Services* (M. Fischer, M. Rounsevell, A. Torre-Marin Rando, A. Mader, A. Church, M. Elbakidze, V. Elias, T. Hahn, P. A. Harrison, J. Hauck, B. Martín-López, I. Ring, C. Sandström, I. Sousa Pinto, P. Visconti, N. E. Zimmermann, & M. Christie, Eds.). IPBES secretariat, Bonn, Germany, 44pp. doi: 10.5281/zenodo.3237411

IPBES (2018b). *The IPBES assessment report on land degradation and restoration* (L. Montanarella, R. Scholes, & A. Brainich, Eds.). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany, 744pp. doi: 10.5281/zenodo.3237392

IPBES (2019). *Global assessment report on biodiversity and ecosystem services* (E. S. Brondizio, J. Settele, S. Díaz, & H. T. Ngo, Eds.). IPBES secretariat, Bonn, Germany, 1148 pages. doi: 10.5281/zenodo.3831673

IPCC (2022a). *Climate Change 2022: Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley, Eds.). Cambridge University Press. Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926

IPCC (2022b). Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3-33. doi: 10.1017/9781009325844.001

Ismail N. A., Kasmuri N., and Hamzah N. (2022). Microbial Bioremediation Techniques for Polycyclic Aromatic Hydrocarbon (PAHs)—a Review. *Water, Air, & Soil Pollution, 233*(4), 124. doi: 10.1007/s11270-022-05598-6

Ivčević A., Mazurek H., Siame L., Bertoldo R., Statzu V., Agharroud K., Estrela Rego I., Mukherjee N., and Bellier O. (2021). Lessons learned about the importance of raising risk awareness in the Mediterranean region (north Morocco and west Sardinia, Italy). *Natural Hazards and Earth System Sciences, 21*(12), 3749–3765. doi: 10.5194/nhess-21-3749-2021

Jiménez J. A., Gracia V., Valdemoro H. I., Mendoza E. T., and Sánchez-Arcilla A. (2011). Managing erosion-induced problems in NW Mediterranean urban beaches. *Ocean & Coastal Management, 54*(12), 907–918. doi: 10.1016/j.ocecoaman.2011.05.003

Jiménez J. A., and Valdemoro H. I. (2019). Shoreline Evolution and its Management Implications in Beaches Along the Catalan Coast. In J. A. Morales (Ed.), *The Spanish Coastal Systems: Dynamic Processes, Sediments and Management* (pp. 745–764). Springer International Publishing. doi: 10.1007/978-3-319-93169-2_32

Karydis M., and Kitsiou D. (2012). Eutrophication and environmental policy in the Mediterranean Sea: a review. *Environmental Monitoring and Assessment, 184*(8), 4931–4984. doi: 10.1007/s10661-011-2313-2

Katsanevakis S., Wallentinus I., Zenetos A., Leppäkoski E., Çinar M. E., Oztürk B., Grabowski M., Golani D., and Cardoso A. C. (2014). Impacts of invasive alien marine species on ecosystem services and biodiversity: a pan-European review. *Aquatic Invasions, 9*(4), 391–423. doi: 10.3391/ai.2014.9.4.01

Kim G.-U., Seo K.-H., and Chen D. (2019). Climate change over the Mediterranean and current destruction of marine ecosystem. *Scientific Reports, 9*(1), 18813. doi: 10.1038/s41598-019-55303-7

Kiparissis S., Fakiris E., Papatheodorou G., Geraga M., Kornaros M., Kapareliotis A., and Ferentinos G. (2011). Illegal trawling and induced invasive algal spread as collaborative factors in a Posidonia oceanica meadow degradation. *Biological Invasions, 13*(3), 669–678. doi: 10.1007/s10530-010-9858-9

Kolekar K. A., Hazra T., and Chakrabarty S. N. (2016). A Review on Prediction of Municipal Solid Waste Generation Models. *Procedia Environmental Sciences, 35,* 238–244. doi: 10.1016/j.proenv.2016.07.087

Kougias I., Bódis K., Jäger-Waldau A., Moner-Girona M., Monforti-Ferrario F., Ossenbrink H., and Szabó S. (2016). The potential of water infrastructure to accommodate solar PV systems in Mediterranean islands. *Solar Energy, 136,* 174–182. doi: 10.1016/j.solener.2016.07.003

Kourgialas N. N. (2021). A critical review of water resources in Greece: The key role of agricultural adaptation to climate-water effects. *Science of The Total Environment, 775,* 145857. doi: 10.1016/j.scitotenv.2021.145857

Kousteni V., Tsiamis K., Gervasini E., Zenetos A., Karachle P. K., and Cardoso A. C. (2022). Citizen scientists contributing to alien species detection: the case of fishes and mollusks in European marine waters. *Ecosphere, 13*(1). doi: 10.1002/ecs2.3875

Kyprioti A., Almpanidou V., Chatzimentor A., Katsanevakis S., and Mazaris A. D. (2021). Is the current Mediterranean network of marine protected areas resilient to climate change? *Science of The Total Environment, 792,* 148397. doi: 10.1016/j.scitotenv.2021.148397

Lacoue-Labarthe T., Nunes P. A. L. D., Ziveri P., Cinar M., Gazeau F., Hall-Spencer J. M., Hilmi N., Moschella P., Safa A., Sauzade D., and Turley C. (2016). Impacts of ocean acidification in a warming Mediterranean Sea: An overview. *Regional Studies in Marine Science, 5,* 1–11. doi: 10.1016/j.rsma.2015.12.005

Lavrnić S., Zapater-Pereyra M., and Mancini M. L. (2017). Water Scarcity and Wastewater Reuse Standards in Southern Europe: Focus on Agriculture. *Water, Air, & Soil Pollution, 228*(7), 251. doi:10.1007/s11270-017-3425-2

Le Cozannet G., Nicholls R., Hinkel J., Sweet W., McInnes K., Van De Wal R., Slangen A., Lowe J., and White K. (2017). Sea Level Change and Coastal Climate Services: The Way Forward. *Journal of Marine Science and Engineering*, *5*(4), 49. doi: 10.3390/jmse5040049

Lebreton L. C.-M., Greer S. D., and Borrero J. C. (2012). Numerical modelling of floating debris in the world's oceans. *Marine Pollution Bulletin*, *64*(3), 653–661. doi: 10.1016/j.marpolbul.2011.10.027

Leogrande R., Vitti C., Vonella A. V., and Ventrella D. (2020). Crop and Soil Response to Organic Management Under Mediterranean Conditions. *International Journal of Plant Production*, *14*(2), 209–220. doi: 10.1007/s42106-019-00079-z

Leruste A., Malet N., Munaron D., Derolez V., Hatey E., Collos Y., De Wit R., and Bec B. (2016). First steps of ecological restoration in Mediterranean lagoons: Shifts in phytoplankton communities. *Estuarine, Coastal and Shelf Science, 180,* 190–203. doi: 10.1016/j.ecss.2016.06.029

Leza M., Herrera C., Picó G., Morro T., and Colomar V. (2021). Six years of controlling the invasive species Vespa velutina in a Mediterranean island: The promising results of an eradication plan. *Pest Management Science*, *77*(5), 2375–2384. doi: 10.1002/ps.6264

Linares C., Sánchez R., Mirón I. J., and Díaz J. (2015). Has there been a decrease in mortality due to heat waves in Spain? Findings from a multicity case study. *Journal of Integrative Environmental Sciences, 12*(2), 153–163. doi: 10.1080/1943815x.2015.1062032

Lincke D., and Hinkel J. (2018). Economically robust protection against 21st century sea-level rise. *Global Environmental Change, 51,* 67–73. doi: 10.1016/j.gloenvcha.2018.05.003

Lincke D., Wolff C., Hinkel J., Vafeidis A., Blickensdörfer L., and Povh Skugor D. (2020). The effectiveness of setback zones for adapting to sea-level rise in Croatia. *Regional Environmental Change, 20*(2), 46. doi: 10.1007/s10113-020-01628-3

Lionello P., Nicholls R. J., Umgiesser G., and Zanchettin D. (2021). Venice flooding and sea level: past evolution, present issues, and future projections (introduction to the special issue). *Natural Hazards and Earth System Sciences, 21*(8), 2633–2641. doi: 10.5194/nhess-21-2633-2021

Llorca M., Álvarez-Muñoz D., Ábalos M., Rodríguez-Mozaz S., Santos L. H. M. L. M., León V. M., Campillo J. A., Martínez-Gómez C., Abad E., and Farré M. (2020). Microplastics in Mediterranean coastal area: toxicity and impact for the environment and human health. *Trends in Environmental Analytical Chemistry, 27,* e00090. doi: 10.1016/j.teac.2020.e00090

Löhr A., Savelli H., Beunen R., Kalz M., Ragas A., and Van Belleghem F. (2017). Solutions for global marine litter pollution. *Current Opinion in Environmental Sustainability, 28,* 90–99. doi: 10.1016/j.cosust.2017.08.009

López-Dóriga U., and Jiménez J. A. (2020). Impact of Relative Sea-Level Rise on Low-Lying Coastal Areas of Catalonia, NW Mediterranean, Spain. *Water, 12*(11), 3252. doi: 10.3390/w12113252

Malagó A., Bouraoui F., Grizzetti B., and De Roo A. (2019). Modelling nutrient fluxes into the Mediterranean Sea. *Journal of Hydrology: Regional Studies, 22,* 100592. doi: 10.1016/j.ejrh.2019.01.004

Malagó A., Comero S., Bouraoui F., Kazezyılmaz-Alhan C. M., Gawlik B. M., Easton P., and Laspidou C. (2021). An analytical framework to assess SDG targets within the context of WEFE nexus in the Mediterranean region. *Resources, Conservation and Recycling, 164,* 105205. doi: 10.1016/j.resconrec.2020.105205

Malek Ž., and Verburg P. H. (2018). Adaptation of land management in the Mediterranean under scenarios of irrigation water use and availability. *Mitigation and Adaptation Strategies for Global Change, 23*(6), 821–837. doi: 10.1007/s11027-017-9761-0

Markantonis V., Reynaud A., Karabulut A., El Hajj R., Altinbilek D., Awad I. M., Bruggeman A., Constantianos V., Mysiak J., Lamaddalena N., Matoussi M. S., Monteiro H., Pistocchi A., Pretato U., Tahboub N., Tunçok I. K., Ünver O., Van Ek R., Willaarts B., … Bidoglio G. (2019). Can the Implementation of the Water-Energy-Food Nexus Support Economic Growth in the Mediterranean Region? The Current Status and the Way Forward. *Frontiers in Environmental Science, 7,* 84. doi: 10.3389/fenvs.2019.00084

Martínez-Guijarro R., Paches M., Romero I., and Aguado D. (2019). Enrichment and contamination level of trace metals in the Mediterranean marine sediments of Spain. *Science of The Total Environment, 693,* 133566. doi: 10.1016/j.scitotenv.2019.07.372

Martínez-Sánchez M. J., Pérez-Sirvent C., Garcia-Lorenzo M. L., Martínez-Lopez S., Bech J., Hernandez C., Martínez L. B., and Molina J. (2017). Ecoefficient In Situ Technologies for the Remediation of Sites Affected by Old Mining Activities: The Case of Portman Bay. In J. Bech, C. Bini, & M. A. Pashkevich (Eds.), *Assessment, Restoration and Reclamation of Mining Influenced Soils* (pp. 355–373). Elsevier. doi: 10.1016/B978-0-12-809588-1.00013-x

Masria A., Iskander M., and Negm A. (2015). Coastal protection measures, case study (Mediterranean zone, Egypt). *Journal of Coastal Conservation, 19*(3), 281–294. doi: 10.1007/s11852-015-0389-5

Mastrocicco M., and Colombani N. (2021). The Issue of Groundwater Salinization in Coastal Areas of the Mediterranean Region: A Review. *Water, 13*(1), 90. doi: https://doi.org/10.3390/w13010090

Mata-Lima H., Alvino-Borba A., Vasquez I. Y. S., Da Silva J. J., Incau B. H., and Almeida J. A. (2017). Minimizing disruptions caused by damming and ensuring the health of downstream ecosystems. Environmental Quality Management, 27(1), 41–48. doi: 10.1002/tqem.21516

Mauchamp A., Chauvelon P., and Grillas P. (2002). Restoration of floodplain wetlands: Opening polders along a coastal river in Mediterranean France, Vistre marshes. *Ecological Engineering, 18*(5), 619–632. doi: 10.1016/S0925-8574(02)00024-1

McEvoy S., Haasnoot M., and Biesbroek R. (2021). How are European countries planning for sea level rise? *Ocean & Coastal Management, 203,* 105512. doi: 10.1016/j.ocecoaman.2020.105512

McNamara C. J., Anastasiou C. C., O'Flaherty V., and Mitchell R. (2008). Bioremediation of olive mill wastewater. *International Biodeterioration & Biodegradation, 61*(2), 127–134. doi: 10.1016/j.ibiod.2007.11.003

MedECC (2020). *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report* (W. Cramer, J. Guiot, & K. Marini, Eds.). Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, 632 pp. doi: 10.5281/zenodo.4768833

MedPAN, and UNEP/MAP-SPA/RAC. (2023). *The 2020 Status of Marine Protected Areas in the Mediterranean* (R. Neveu, D. Ganot, F. Ducarme, S. El Asmi, A. Kheriji, & S. Gallon, Eds.). UNEP/MAP-SPA/RAC & MedPAN. Tunis 147 pages+Annexes. https://medpan.org/en/system-mediterranean-mpas-2020

Méndez A., Gómez A., Paz-Ferreiro J., and Gascó G. (2012). Effects of sewage sludge biochar on plant metal availability after application to a Mediterranean soil. *Chemosphere, 89*(11), 1354–1359. doi: 10.1016/j.chemosphere.2012.05.092

Mentzafou A., Vamvakaki C., Zacharias I., Gianni A., and Dimitriou E. (2017). Climate change impacts on a Mediterranean river and the associated interactions with the adjacent coastal area. *Environmental Earth Sciences, 76*(6), 259. doi: 10.1007/s12665-017-6572-2

Merchichi A., Hamou M. O., Edahbi M., Bobocioiu E., Neculita C. M., and Benzaazoua M. (2022). Passive treatment of acid mine drainage from the Sidi-Kamber mine wastes (Mediterranean coastline, Algeria) using neighbouring phosphate material from the Djebel Onk mine. *Science of The Total Environment, 807,* 151002. doi: 10.1016/j.scitotenv.2021.151002

Merhaby D., Rabodonirina S., Net S., Ouddane B., and Halwani J. (2019). Overview of sediments pollution by PAHs and PCBs in mediterranean basin: Transport, fate, occurrence, and distribution. In *Marine Pollution Bulletin, 149,* 220646 doi: 10.1016/j.marpolbul.2019.110646

Mohamed M. A. E., Mohamed S. M. R., Saied E. M. M., Elsisi M., Su C. L., and Hadi H. A. (2022). Optimal Energy Management Solutions Using Artificial Intelligence Techniques for Photovoltaic Empowered Water Desalination Plants Under Cost Function Uncertainties. *IEEE Access, 10,* 93646–93658. doi: 10.1109/access.2022.3203692

Molina R., Manno G., Lo Re C., Anfuso G., and Ciraolo G. (2020). A Methodological Approach to Determine Sound Response Modalities to Coastal Erosion Processes in Mediterranean Andalusia (Spain). *Journal of Marine Science and Engineering, 8*(3), 154. doi: 10.3390/jmse8030154

Möller P., De Lucia M., Rosenthal E., Inbar N., Salameh E., Magri F., and Siebert C. (2020). Sources of Salinization of Groundwater in the Lower Yarmouk Gorge, East of the River Jordan. *Water, 12*(5), 1291. doi: 10.3390/w12051291

Morote Á.-F., Olcina J., and Hernández M. (2019). The Use of Non-Conventional Water Resources as a Means of Adaptation to Drought and Climate Change in Semi-Arid Regions: South-Eastern Spain. *Water, 11*(1), 93. doi: 10.3390/w11010093

Morseletto P. (2020). A new framework for policy evaluation: Targets, marine litter, Italy and the Marine Strategy Framework Directive. *Marine Policy, 117,* 103956. doi: 10.1016/j.marpol.2020.103956

Nader M. R., Indary S., and Boustany L. E. (2012). *FAO EastMed The puffer fish Lagocephalus sceleratus (Gmelin, 1789) in the Eastern Mediterranean.* GCP/INT/041/EC – GRE – ITA/TD-10. FAO, Athens (Greece). https://openknowledge.fao.org/handle/20.500.14283/ap967e

Narayan S., Beck M. W., Reguero B. G., Losada I. J., van Wesenbeeck B., Pontee N., Sanchirico J. N., Ingram J. C., Lange G.-M., and Burks-Copes K. A. (2016). The Effectiveness, Costs and Coastal Protection Benefits of Natural and Nature-Based Defences. *PLOS ONE, 11*(5), e0154735. doi: 10.1371/journal.pone.0154735

Nour H. E., El-Sorogy A. S., El-Wahab M. A., Nouh E. S., Mohamaden M., and Al-Kahtany K. (2019). Contamination and ecological risk assessment of heavy metals pollution from the Shalateen coastal sediments, Red Sea, Egypt. *Marine Pollution Bulletin, 144,* 167–172. https://doi.org/10.1016/j.marpolbul.2019.04.056

Nourisson D. H., Scapini F., and Milstein A. (2018). Small-scale changes of an arthropod beach community after hard-engineering interventions on a Mediterranean beach. *Regional Studies in Marine Science, 22,* 21–30. doi: 10.1016/j.rsma.2018.05.005

Okbah M. A., Nasr S. M., Soliman N. F., and Khairy M. A. (2014). Distribution and Contamination Status of Trace Metals in the Mediterranean Coastal Sediments, Egypt. *Soil and Sediment Contamination: An International Journal, 23*(6), 656–676. doi: 10.1080/15320383.2014.851644

Olazabal M., Ruiz de Gopegui M., Tompkins E. L., Venner K., and Smith R. (2019). A cross-scale worldwide analysis of coastal adaptation planning. *Environmental Research Letters, 14*(12), 124056. doi: 10.1088/1748-9326/ab5532

Oppenheimer M., Oreskes N., Jamieson D., Brysse K., O'Reilly J., Shindell M., and Wazeck M. (2019). *Discerning experts: The practices of scientific assessment for environmental policy.* University of Chicago Press. doi: 10.7208/chicago/9780226602158.001.0001

Ozer T., Rahav E., Gertman I., Sisma-Ventura G., Silverman J., and Herut B. (2022). Relationship between thermohaline and biochemical patterns in the levantine upper and intermediate water masses, Southeastern Mediterranean Sea (2013–2021). *Frontiers in Marine Science, 9,* 958924. doi: 10.3389/fmars.2022.958924

PAP/RAC (2019). *The Governance of Coastal Wetlands in the Mediterranean: A Handbook.* (B. Shipman & Ž. Rajković, Eds). Split, Croatia. https://paprac.org/news/item/governance-coastal-wetlands-mediterranean-handbook-published

PAP/RAC. (2021). *Coastal Resilience Handbook for the Adriatic - AdriAdapt* (A. I. Hudi, D. Povh Škugor, & I. Sekovski, Eds.). INTERREG AdriAdapt project, Split. https://adriadapt.eu/guidelines/coastal-resilience-handbook-for-the-adriatic/

Parkhurst J. (2016). *The Politics of Evidence: From evidence-based policy to the good governance of evidence* (1st ed.). Routledge. https://www.taylorfrancis.com/books/9781315675008

Parmesan C., Morecroft M. D., Trisurat Y., Adrian R., Anshari G. Z., Arneth A., Gao Q., Gonzalez P., Harris R., Price J., Stevens N., and Talukdarr G. H. (2022). Terrestrial and Freshwater Ecosystems and Their Services. In H. O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 197-377. doi: 10.1017/9781009325844.004

Pedrero F., Kalavrouziotis I., Alarcón J. J., Koukoulakis P., and Asano T. (2010). Use of treated municipal wastewater in irrigated agriculture—Review of some practices in Spain and Greece. *Agricultural Water Management, 97*(9), 1233–1241. doi: 10.1016/j.agwat.2010.03.003

Pedrotti M. L., Lombard F., Baudena A., Galgani F., Elineau A., Petit S., Henry M., Troublé R., Reverdin G., Ser-Giacomi E., Kedzierski M., Boss E., and Gorsky G. (2022). An integrative assessment of the plastic debris load in the Mediterranean Sea. *Science of The Total Environment, 838,* 155958. doi: 10.1016/j.scitotenv.2022.155958

Peñacoba-Antona L., Ramirez-Vargas C. A., Wardman C., Carmona-Martinez A. A., Esteve-Núñez A., Paredes D., Brix H., and Arias C. A. (2022). Microbial Electrochemically Assisted Treatment Wetlands: Current Flow Density as a Performance Indicator in Real-Scale Systems in Mediterranean and Northern European Locations. *Frontiers in Microbiology, 13,* 843135. doi: 10.3389/fmicb.2022.843135

Petersen J. K., Hasler B., Timmermann K., Nielsen P., Tørring D. B., Larsen M. M., and Holmer M. (2014). Mussels as a tool for mitigation of nutrients in the marine environment. *Marine Pollution Bulletin, 82*(1–2), 137–143. doi: 10.1016/j.marpolbul.2014.03.006

Phong Vo H. N., Ngo H. H., Guo W., Hong Nguyen T. M., Li J., Liang H., Deng L., Chen Z., and Hang Nguyen T. A. (2020). Poly–and perfluoroalkyl substances in water and wastewater: A comprehensive review from sources to remediation. *Journal of Water Process Engineering, 36,* 101393. doi: 10.1016/j.jwpe.2020.101393

Pinto C. A., Silveira T. M., and Teixeira S. B. (2020). Beach nourishment practice in mainland Portugal (1950–2017): Overview and retrospective. *Ocean & Coastal Management, 192,* 105211. doi: 10.1016/j.ocecoaman.2020.105211

Pirani S. I., and Arafat H. A. (2014). Solid waste management in the hospitality industry: A review. *Journal of Environmental Management, 146,* 320–336. doi: 10.1016/j.jenvman.2014.07.038

Pittura L., Avio C. G., Giuliani M. E., d'Errico G., Keiter S. H., Cormier B., Gorbi S., and Regoli F. (2018). Microplastics as Vehicles of Environmental PAHs to Marine Organisms: Combined Chemical and Physical Hazards to the Mediterranean Mussels, Mytilus galloprovincialis. *Frontiers in Marine Science, 5,* 103. doi: 10.3389/fmars.2018.00103

Portillo Juan N., Negro Valdecantos V., and Del Campo J. M. (2022). Review of the Impacts of Climate Change on Ports and Harbours and Their Adaptation in Spain. *Sustainability, 14*(12), 7507. doi: 10.3390/su14127507

Portman M. E., Esteves L. S., Le X. Q., and Khan A. Z. (2012). Improving integration for integrated coastal zone management: An eight country study. Science of The Total Environment, 439, 194–201. doi: 10.1016/j.scitotenv.2012.09.016

Pranzini E. (2018). Shore protection in Italy: From hard to soft engineering … and back. *Ocean & Coastal Management, 156,* 43–57. doi: 10.1016/j.ocecoaman.2017.04.018

Pranzini E., Wetzel L., and Williams A. T. (2015). Aspects of coastal erosion and protection in Europe. *Journal of Coastal Conservation, 19*(4), 445–459. doi: 10.1007/s11852-015-0399-3

Prevedouros K., Cousins I. T., Buck R. C., and Korzeniowski S. H. (2006). Sources, Fate and Transport of Perfluorocarboxylates. *Environmental Science & Technology, 40*(1), 32–44. doi: 10.1021/es0512475

Pueyo-Ros J., Garcia X., Ribas A., and Fraguell R. M. (2018). Ecological Restoration of a Coastal Wetland at a Mass Tourism Destination. Will the Recreational Value Increase or Decrease? *Ecological Economics, 148,* 1–14. doi: 10.1016/j.ecolecon.2018.02.002

Pulido-Bosch A., Vallejos A., and Sola F. (2019). Methods to supply seawater to desalination plants along the Spanish mediterranean coast and their associated issues. *Environmental Earth Sciences, 78*(10), 322. doi: 10.1007/s12665-019-8298-9

Pulido-Velazquez D., Romero J., Collados-Lara A. J., Alcalá F. J., Fernández-Chacón F., and Baena-Ruiz L. (2020). Using the Turnover Time Index to Identify Potential Strategic Groundwater Resources to Manage Droughts within Continental Spain. *Water 2020, Vol. 12, Page 3281, 12*(11), 3281. doi: 10.3390/w12113281

Range P., Chícharo M. A., Ben-Hamadou R., Piló D., Fernandez-Reiriz M. J., Labarta U., Marin M. G., Bressan M., Matozzo V., Chinellato A., Munari M., El Menif N. T., Dellali M., and Chícharo L. (2014). Impacts of CO2-induced seawater acidification on coastal Mediterranean bivalves and interactions with other climatic stressors. *Regional Environmental Change, 14*(S1), 19–30. doi: 10.1007/s10113-013-0478-7

Ranieri E., Montanaro C., Ranieri A. C., Campanaro V., and Cioca L.-I. (2017). Municipal solid wastes in the South-Eastern Mediterranean region: Quality, quantity and management. *CALITATEA-ACCES LA SUCCES, 18,* 162–169. https://hdl.handle.net/11589/118308

Reckien D., Buzasi A., Olazabal M., Spyridaki N.-A., Eckersley P., Simoes S. G., Salvia M., Pietrapertosa F., Fokaides P., Goonesekera S. M., Tardieu L., Balzan M. V., de Boer C. L., De Gregorio Hurtado S., Feliu E., Flamos A., Foley A., Geneletti D., Grafakos S., … Wejs A. (2023). Quality of urban climate adaptation plans over time. *Npj Urban Sustainability, 3*(1), 13. doi: 10.1038/s42949-023-00085-1

Reimann L., Merkens J. L., and Vafeidis A. T. (2018). Regionalized Shared Socioeconomic Pathways: narratives and spatial population projections for the Mediterranean coastal zone. *Regional Environmental Change, 18*(1). doi: 10.1007/s10113-017-1189-2

Rey-Valette H., Robert S., and Rulleau B. (2019). Resistance to relocation in flood-vulnerable coastal areas: a proposed composite index. *Climate Policy, 19*(2), 206–218. doi: 10.1080/14693062.2018.1482823

Ricart S., Villar-Navascués R. A., Hernández-Hernández M., Rico-Amorós A. M., Olcina-Cantos J., and Moltó-Mantero E. (2021). Extending Natural Limits to Address Water Scarcity? The Role of Non-Conventional Water Fluxes in Climate Change Adaptation Capacity: A Review. *Sustainability 2021, Vol. 13, Page 2473, 13*(5), 2473. doi: 10.3390/su13052473

Rilov G., Fraschetti S., Gissi E., Pipitone C., Badalamenti F., Tamburello L., Menini E., Goriup P., Mazaris A. D., Garrabou J., Benedetti–Cecchi L., Danovaro R., Loiseau C., Claudet J., and Katsanevakis S. (2020). A fast–moving target: achieving marine conservation goals under shifting climate and policies. *Ecological Applications, 30*(1). doi: 10.1002/eap.2009

Robert S., and Schleyer-Lindenmann A. (2021). How ready are we to cope with climate change? Extent of adaptation to sea level rise and coastal risks in local planning documents of southern France. *Land Use Policy, 104*, 105354. doi: 10.1016/j.landusepol.2021.105354

Rocle N., Dachary-Bernard J., and Rey-Valette H. (2021). Moving towards multi-level governance of coastal managed retreat: Insights and prospects from France. *Ocean & Coastal Management, 213*, 105892. doi: 10.1016/j.ocecoaman.2021.105892

Rodríguez-Escales P., Canelles A., Sanchez-Vila X., Folch A., Kurtzman D., Rossetto R., Fernández-Escalante E., Lobo-Ferreira J.-P., Sapiano M., San-Sebastián J., and Schüth C. (2018). A risk assessment methodology to evaluate the risk failure of managed aquifer recharge in the Mediterranean Basin. *Hydrology and Earth System Sciences, 22*(6), 3213–3227. doi: 10.5194/hess-22-3213-2018

Rodríguez-Santalla I., and Navarro N. (2021). Main Threats in Mediterranean Coastal Wetlands. The Ebro Delta Case. *Journal of Marine Science and Engineering, 9*(11), 1190. doi: 10.3390/jmse9111190

Roig A., Cayuela M. L., and Sánchez-Monedero M. A. (2006). An overview on olive mill wastes and their valorisation methods. *Waste Management, 26*(9), 960–969. doi: 10.1016/j.wasman.2005.07.024

Rotini A., Chiesa S., Manfra L., Borrello P., Piermarini R., Silvestri C., Cappucci S., Parlagreco L., Devoti S., Pisapia M., Creo C., Mezzetti T., Scarpato A., and Migliore L. (2020). Effectiveness of the "Ecological Beach" Model: Beneficial Management of Posidonia Beach Casts and Banquette. *Water, 12*(11), 3238. doi: 10.3390/w12113238

Ruffault J., Curt T., Martin-StPaul N. K., Moron V., and Trigo R. M. (2018). Extreme wildfire events are linked to global-change-type droughts in the northern Mediterranean. *Natural Hazards and Earth System Sciences, 18*(3), 847–856. doi: 10.5194/nhess-18-847-2018

Ruiz-Campillo X., Gil O., and García Fernández C. (2022). Ready for Climate Change? An Assessment of Measures Adopted by 45 Mediterranean Coastal Cities to Face Climate Change. In W. Leal Filho & E. Manolas (Eds.), *Climate Change in the Mediterranean and Middle Eastern Region* (pp. 269–291). Springer International Publishing. https://link.springer.com/10.1007/978-3-030-78566-6_13

Ruiz-Frau A., Krause T., and Marbà N. (2019). In the blind-spot of governance – Stakeholder perceptions on seagrasses to guide the management of an important ecosystem services provider. *Science of The Total Environment, 688*, 1081–1091. doi: 10.1016/j.scitotenv.2019.06.324

Russo A., Gouveia C. M., Dutra E., Soares P. M. M., and Trigo R. M. (2019). The synergy between drought and extremely hot summers in the Mediterranean. *Environmental Research Letters, 14*(1), 014011. https://doi.org/10.1088/1748-9326/aaf09e

Said A., Tzanopoulos J., and MacMillan D. (2018). The Contested Commons: The Failure of EU Fisheries Policy and Governance in the Mediterranean and the Crisis Enveloping the Small-Scale Fisheries of Malta. *Frontiers in Marine Science, 5*, 300. doi: 10.3389/fmars.2018.00300

Samaras A., and Karambas T. (2021). Modelling the Impact of Climate Change on Coastal Flooding: Implications for Coastal Structures Design. *Journal of Marine Science and Engineering, 9*(9), 1008. doi: 10.3390/jmse9091008

Sánchez-Arcilla A., Cáceres I., Roux X. Le, Hinkel J., Schuerch M., Nicholls R. J., Otero D. M., Staneva J., De Vries M., Pernice U., Briere C., Caiola N., Gracia V., Ibáñez C., and Torresan S. (2022). Barriers and enablers for upscaling coastal restoration. *Nature-Based Solutions, 2*, 100032. doi: 10.1016/j.nbsj.2022.100032

Santana M. S., Sandrini-Neto L., Filipak Neto F., Oliveira Ribeiro C. A., Di Domenico M., and Prodocimo M. M. (2018). Biomarker responses in fish exposed to polycyclic aromatic hydrocarbons (PAHs): Systematic review and meta-analysis. *Environmental Pollution, 242*, 449–461. https://doi.org/10.1016/j.envpol.2018.07.004

Sauer I., Roca E., and Villares M. (2022). Beach Users' Perceptions of Coastal Regeneration Projects as An Adaptation Strategy in The Western Mediterranean. *Journal of Hospitality & Tourism Research, 46*(3), 418–441. doi: 10.1177/1096348019889112

Schleyer-Lindenmann A., Mudaliar R., Rishi P., and Robert S. (2022). Climate change and adaptation to coastal risks as perceived in two major coastal cities: An exploratory study in Marseilles and Nice (France). *Ocean & Coastal Management, 225,* 106209. doi: 10.1016/j.ocecoaman.2022.106209

Schoonees T., Gijón Mancheño A., Scheres B., Bouma T. J., Silva R., Schlurmann T., and Schüttrumpf H. (2019). Hard Structures for Coastal Protection, Towards Greener Designs. *Estuaries and Coasts, 42(7),* 1709–1729. doi: 10.1007/S12237-019-00551-z

Schuerch M., Mossman H. L., Moore H. E., Christie E., and Kiesel J. (2022). Invited perspectives: Managed realignment as a solution to mitigate coastal flood risks – optimizing success through knowledge co-production. *Natural Hazards and Earth System Sciences, 22*(9), 2879–2890. doi: 10.5194/nhess-22-2879-2022

Schuerch M., Spencer T., Temmerman S., Kirwan M. L., Wolff C., Lincke D., McOwen C. J., Pickering M. D., Reef R., Vafeidis A. T., Hinkel J., Nicholls R. J., and Brown S. (2018). Future response of global coastal wetlands to sea-level rise. *Nature*, *561*(7722), 231–234. doi: 10.1038/s41586-018-0476-5

Sedano F., Pavón-Paneque A., Navarro-Barranco C., Guerra-García J. M., Digenis M., Sempere-Valverde J., and Espinosa F. (2021). Coastal armouring affects intertidal biodiversity across the Alboran Sea (Western Mediterranean Sea). *Marine Environmental Research, 171,* 105475. doi: 10.1016/j.marenvres.2021.105475

Sfriso A., Buosi A., Facca C., Sfriso A. A., Tomio Y., Juhmani A.-S., Wolf M. A., Franzoi P., Scapin L., Ponis E., Cornello M., Rampazzo F., Berto D., Gion C., Oselladore F., Boscolo Brusà R., and Bonometto A. (2021). Environmental restoration by aquatic angiosperm transplants in transitional water systems: The Venice Lagoon as a case study. *Science of The Total Environment, 795,* 148859. doi: 10.1016/j.scitotenv.2021.148859

Shabtay A., Portman M. E., and Carmel Y. (2018). Contributions of marine infrastructures to marine planning and protected area networking. *Aquatic Conservation: Marine and Freshwater Ecosystems, 28*(4), 830–839. doi: 10.1002/aqc.2916

Shabtay A., Portman M. E., Manea E., and Gissi E. (2019). Promoting ancillary conservation through marine spatial planning. *Science of The Total Environment, 651,* 1753–1763. doi: 10.1016/j.scitotenv.2018.10.074

Shalby A., Elshemy M., and Zeidan B. A. (2020). Assessment of climate change impacts on water quality parameters of Lake Burullus, Egypt. *Environmental Science and Pollution Research, 27*(26), 32157–32178. doi: 10.1007/s11356-019-06105-x

Sharaan M., Iskander M., and Udo K. (2022). Coastal adaptation to Sea Level Rise: An overview of Egypt's efforts. *Ocean & Coastal Management, 218,* 106024. doi: 10.1016/j.ocecoaman.2021.106024

Sharaan M., and Udo K. (2020). Projections of future beach loss along the mediterranean coastline of Egypt due to sea-level rise. *Applied Ocean Research, 94,* 101972. doi: 10.1016/j.apor.2019.101972

Sienkiewicz M., and Mair D. (2020). Against the Science–Policy Binary Separation: Science for Policy 1.0. *Science for Policy Handbook, 2–13.* doi: 10.1016/B978-0-12-822596-7.00001-2

Simeone S., Palombo A. G. L., Antognarelli F., Brambilla W., Conforti A., and De Falco G. (2022). Sediment Budget Implications from Posidonia oceanica Banquette Removal in a Starved Beach System. *Water, 14*(15), 2411. doi: 10.3390/w14152411

Simon-Sánchez L., Grelaud M., Lorenz C., Garcia-Orellana J., Vianello A., Liu F., Vollertsen J., and Ziveri P. (2022). Can a Sediment Core Reveal the Plastic Age? Microplastic Preservation in a Coastal Sedimentary Record. *Environmental Science & Technology, 56*(23), 16780–16788. doi: 10.1021/acs.est.2c04264

Soria J., Pérez R., and Sòria-Pepinyà X. (2022). Mediterranean Coastal Lagoons Review: Sites to Visit before Disappearance. *Journal of Marine Science and Engineering, 10*(3), 347. doi: 10.3390/jmse10030347

Spiteri C., Roddier-Quefelec C., Giraud J.-P., and Hema T. (2016). Assessing the progress in depolluting the Mediterranean Sea. *Marine Pollution Bulletin, 102*(2), 295–308. doi: 10.1016/j.marpolbul.2015.08.009

Stadmark J., and Conley D. J. (2011). Mussel farming as a nutrient reduction measure in the Baltic Sea: Consideration of nutrient biogeochemical cycles. *Marine Pollution Bulletin, 62*(7), 1385–1388. doi: 10.1016/j.marpolbul.2011.05.001

Stamatis N., Kamidis N., Pigada P., Sylaios G., and Koutrakis E. (2019). Quality Indicators and Possible Ecological Risks of Heavy Metals in the Sediments of three Semi-closed East Mediterranean Gulfs. *Toxics, 7*(2), 30. doi: 10.3390/toxics7020030

Suaria G., Avio C. G., Mineo A., Lattin G. L., Magaldi M. G., Belmonte G., Moore C. J., Regoli F., and Aliani S. (2016). The Mediterranean Plastic Soup: Synthetic polymers in Mediterranean surface waters. *Scientific Reports, 6.* doi: 10.1038/srep37551

Šucha V., and Dewar M. (2020). Institutional Framework for the Science–Policy Interaction. In V. Šucha & M. Sienkiewicz (Eds), *Science for Policy Handbook* (pp. 20-30), Elsevier Limited doi:10.1016/b978-0-12-822596-7.00003-6

Tamburello L., Papa L., Guarnieri G., Basconi L., Zampardi S., Scipione M. B., Terlizzi A., Zupo V., and Fraschetti S. (2019). Are we ready for scaling up restoration actions? An insight from Mediterranean macroalgal canopies. *PLOS ONE, 14*(10), e0224477. doi: 10.1371/journal.pone.0224477

Telesca L., Belluscio A., Criscoli A., Ardizzone G., Apostolaki E. T., Fraschetti S., Gristina M., Knittweis L., Martin C. S., Pergent G., Alagna A., Badalamenti F., Garofalo G., Gerakaris V., Louise Pace M., Pergent-Martini C., and Salomidi M. (2015). Seagrass meadows (Posidonia oceanica) distribution and trajectories of change. *Scientific Reports, 5*(1), 12505. doi: https://doi.org/10.1038/srep12505

Thomaidi V., Petousi I., Kotsia D., Kalogerakis N., and Fountoulakis M. S. (2022). Use of green roofs for greywater treatment: Role of substrate, depth, plants, and recirculation. *Science of The Total Environment, 807,* 151004. doi: 10.1016/j.scitotenv.2021.151004

Tourlioti P. N., Portman M. E., Tzoraki O., and Pantelakis I. (2021). Interacting with the coast: Residents' knowledge and perceptions about coastal erosion (Mytilene, Lesvos Island, Greece). *Ocean & Coastal Management, 210*, 105705. doi: 10.1016/j.ocecoaman.2021.105705

Tran T. A. (2017). A research on the energy efficiency operational indicator EEOI calculation tool on M/V NSU JUSTICE of VINIC transportation company, Vietnam. *Journal of Ocean Engineering and Science, 2*(1), 55–60. doi: 10.1016/j.joes.2017.01.001

Tsikoti C., and Genitsaris S. (2021). Review of Harmful Algal Blooms in the Coastal Mediterranean Sea, with a Focus on Greek Waters. *Diversity, 13*(8), 396. doi: 10.3390/d13080396

UNDRR (2017). *The Sendai Framework Terminology on Disaster Risk Reduction. 'Residual risk'.* United Nations International Strategy for Disaster Reduction (UNISDR), Geneva, Switzerland, 30pp. https://www.undrr.org/terminology/residual-risk

UNEP (2021). *Reflecting on the Past and Imagining the Future: A contribution to the dialogue on the Science-Policy Interface [UNEP@50].* https://wedocs.unep.org/20.500.11822/38118

UNEP/MAP (2013). *State of the Mediterranean marine and coastal environment.* UNEP/MAP – Barcelona Convention, Athens. https://www.unep.org/unepmap/resources/publication/state-mediterranean-marine-and-coastal-environment-report-2012

UNEP/MAP (2016a). Decision IG.22/20 Programme of Work and Budget 2016-2017 . In *Report of the 19th Ordinary Meeting of the Contracting Parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean and its Protocols. UNEP(DEPI)/MED IG.22/28* (pp. 709–762). UNEP/MAP, Athens. https://www.unep.org/unepmap/meetings/cop-decisions/cop22-outcome-documents

UNEP/MAP (2016b). *Mediterranean Strategy for Sustainable Development 2016-2025.* Valbonne. Plan Bleu, Regional Activity Centre. https://wedocs.unep.org/bitstream/handle/20.500.11822/7097/mssd_2016_2025_eng.pdf

UNEP/MAP (2017). *Regional Climate Change Adaptation Framework for the Mediterranean Marine and Coastal Areas.* UNEP/MAP, Athens. https://wedocs.unep.org/20.500.11822/17500

UNEP/MAP, and MED POL (2012). *Releases, emissions and sources of pollutants in the Mediterranean region: An assessment of 2003-2008 trends.* United Nations Environment Programme, Mediterranean Action Plan, Athens.

UNEP/MAP, and PAP/RAC (2008). *Protocol on Integrated Coastal Zone Management in the Mediterranean.* UNEP/MAP/RAC-PAP. https://wedocs.unep.org/xmlui/handle/20.500.11822/1747

UNEP/MAP, and Plan Bleu (2019). *Strengthen, structure and sustain a Science Policy Interface (SPI) for IMAP implementation in the Mediterranean.* https://planbleu.org/wp-content/uploads/2019/11/SPI_report_Final.pdf

UNEP/MAP, and Plan Bleu (2020). *State of the Environment and Development in the Mediterranean.* Nairobi. https://planbleu.org/wp-content/uploads/2021/04/SoED_full-report.pdf

Vacchi M., Berriolo G., Schiaffino C. F., Rovere A., Anthony E. A., Corradi N., Firpo M., and Ferrari M. (2020). Assessing the efficacy of nourishment of a Mediterranean beach using bimodal fluvial sediments and a specific placement design. *Geo-Marine Letters, 40*(5), 687–698. doi: 10.1007/s00367-020-00664-6

Valente S., and Veloso-Gomes F. (2020). Coastal climate adaptation in port-cities: adaptation deficits, barriers, and challenges ahead. *Journal of Environmental Planning and Management, 63*(3), 389–414. doi: 10.1080/09640568.2018.1557609

Vallejos A., Sola F., and Pulido-Bosch A. (2015). Processes Influencing Groundwater Level and the Freshwater-Saltwater Interface in a Coastal Aquifer. *Water Resources Management, 29(3),* 679–697. doi: 10.1007/s11269-014-0621-3

Van Rijn L. C. (2011). Coastal erosion and control. *Ocean & Coastal Management, 54(12), 867–887.* doi: 10.1016/j.ocecoaman.2011.05.004

Vera-Herrera L., Romo S., and Soria J. (2022). How Agriculture, Connectivity and Water Management Can Affect Water Quality of a Mediterranean Coastal Wetland. *Agronomy, 12*(2), 486. doi: 10.3390/agronomy12020486

Vicente-Serrano S. M., Zabalza-Martínez J., Borràs G., López-Moreno J. I., Pla E., Pascual D., Savé R., Biel C., Funes I., Azorin-Molina C., Sanchez-Lorenzo A., Martín-Hernández N., Peña-Gallardo M., Alonso-González E., Tomas-Burguera M., and El Kenawy A. (2017). Extreme hydrological events and the influence of reservoirs in a highly regulated river basin of northeastern Spain. *Journal of Hydrology: Regional Studies, 12,* 13–32. doi: 10.1016/j.ejrh.2017.01.004

Visser, L. E. (Ed.). (2004) *Challenging Coasts: Transdisciplinary excursions into integrated coastal zone development.* Amsterdam University Press. http://library.oapen.org/handle/20.500.12657/35124

Vogel J., Paton E., Aich V., and Bronstert A. (2021). Increasing compound warm spells and droughts in the Mediterranean Basin. *Weather and Climate Extremes, 32,* 100312. doi: 10.1016/j.wace.2021.100312

Voukkali I., Loizia P., Navarro Pedreño J., and Zorpas A. A. (2021). Urban strategies evaluation for waste management in coastal areas in the framework of area metabolism. *Waste Management & Research: The Journal for a Sustainable Circular Economy, 39*(3), 448–465. doi: 10.1177/0734242x20972773

Voukkali I., Loizia P., Pociovalisteanu D. M., and Zorpas A. A. (2017). Barriers and Difficulties Concerning the Implementation of an Environmental Management System in a Bakery-Confectionary Industry in Cyprus for 8 Years. *Environmental Processes, 4*(S1), 263–275. doi: 10.1007/s40710-017-0242-y

Wolff C., Nikoletopoulos T., Hinkel J., and Vafeidis A. T. (2020). Future urban development exacerbates coastal exposure in the Mediterranean. *Scientific Reports, 10(1),* 14420. doi: 10.1038/s41598-020-70928-9

Xevgenos D., Marcou M., Louca V., Avramidi E., Ioannou G., Argyrou M., Stavrou P., Mortou M., and Küpper F. C. (2021). Aspects of environmental impacts of seawater desalination: Cyprus as a case study. *Desalination and Water Treatment, 211,* 15–30. doi: 10.5004/dwt.2021.26916

Young J. C., Watt A. D., van den Hove S., and the SPIRAL project team. (2013). *Effective interfaces between science, policy and society: the SPIRAL project handbook.* http://www.spiralproject.eu/content/documents

Ytreberg E., Karlberg M., Hassellöv I.-M., Hedblom M., Nylund A. T., Salo K., Imberg H., Turner D., Tripp L., Yong J., and Wulff A. (2021). Effects of seawater scrubbing on a microplanktonic community during a summer-bloom in the Baltic Sea. *Environmental Pollution, 291,* 118251. doi: 10.1016/j.envpol.2021.118251

Zhang Y., Li M., Dong J., Yang H., Van Zwieten L., Lu H., Alshameri A., Zhan Z., Chen X., Jiang X., Xu W., Bao Y., and Wang H. (2021). A Critical Review of Methods for Analyzing Freshwater Eutrophication. *Water, 13*(2), 225. doi: 10.3390/w13020225

Zhang Y., Svyatsky D., Rowland J. C., Moulton J. D., Cao Z., Wolfram P. J., Xu C., and Pasqualini D. (2022). Impact of Coastal Marsh Eco–Geomorphologic Change on Saltwater Intrusion Under Future Sea Level Rise. *Water Resources Research, 58*(5), e2021WR030333. doi: 10.1029/2021wr030333

Zorpas A. A. (2020). Strategy development in the framework of waste management. *Science of The Total Environment, 716,* 137088. doi: 10.1016/j.scitotenv.2020.137088

Zorpas A. A., Voukkali I., and Navarro Pedreño J. (2018). Tourist area metabolism and its potential to change through a proposed strategic plan in the framework of sustainable development. *Journal of Cleaner Production, 172,* 3609–3620. doi: 10.1016/j.jclepro.2017.02.119

Zscheischler J., Westra S., Van Den Hurk B. J. J. M., Seneviratne S. I., Ward P. J., Pitman A., AghaKouchak A., Bresch D. N., Leonard M., Wahl T., and Zhang X. (2018). Future climate risk from compound events. *Nature Climate Change, 8*(6), 469–477. doi: 10.1038/s41558-018-0156-3

Zuccarello P., Manganelli M., Oliveri Conti G., Copat C., Grasso A., Cristaldi A., De Angelis G., Testai E., Stefanelli M., Vichi S., Fiore M., and Ferrante M. (2021). Water quality and human health: A simple monitoring model of toxic cyanobacteria growth in highly variable Mediterranean hot dry environments. *Environmental Research, 192,* 110291. doi: 10.1016/j.envres.2020.110291

Zviely D., Bitan M., and DiSegni D. M. (2015). The effect of sea-level rise in the 21st century on marine structures along the Mediterranean coast of Israel: An evaluation of physical damage and adaptation cost. *Applied Geography, 57,* 154–162. doi: 10.1016/j.apgeog.2014.12.007

Information about the authors

Coordinating Lead Authors

Mohamed ABDRABO, Alexandria Research Center for Adaptation to Climate Change (ARCA), Alexandria University, *Alexandria, Egypt*

Athanasios T. VAFEIDIS, Institute of Geography, Kiel University, *Kiel, Germany*

Lead Authors

Gonéri Le COZANNET, French Geological Survey (Bureau de Recherche Géologique et Minière, BRGM), *Orléans, France*

Savvas GENITSARIS, National and Kapodistrian University of Athens, *Athens, Greece*

Michelle PORTMAN, Faculty of Architecture and Town Planning, Technion – Israel Institute of Technology, *Haifa, Israel*

Daria POVH ŠKUGOR, UN Environment Programme / Mediterranean Action Plan (UNEP/MAP), Priority Actions Programme Regional Activity Centre (PAP/RAC), *Split, Croatia*

Contributing Authors

Cécile CAPDERREY, French Geological Survey (Bureau de Recherche Géologique et Minière, BRGM), *Orléans, France*

Sinja DITTMANN, Leibniz Institute for Science and Mathematics Education & Institute of Geography, Kiel University, *Kiel, Germany*

Joachim GARRABOU, Institut de Ciències del Mar (ICM-CSIC), Spanish National Research Council (CSIC), *Barcelona, Spain*

Mauricio GONZÁLEZ, IHCantabria – Instituto de Hidráulica Ambiental de La Universidad de Cantabria, *Santander, Spain*

Sebastián MONTSERRAT, Department of Physics, University of the Balearic Islands (UIB), *Palma, Spain*

Marie PETTENATI, French Geological Survey (Bureau de Recherche Géologique et Minière, BRGM), *Orléans, France*

Agustín SÁNCHEZ-ARCILLA, Laboratori d'Enginyeria Marítima, Universitat Politècnica de Catalunya · BarcelonaTech (UPC), *Barcelona, Spain*

Sustainable development pathways

5

Coordinating Lead Authors:
Stefano MONCADA *(Malta)*, **Salpie DJOUNDOURIAN** *(Lebanon)*,
Suzan KHOLEIF *(Egypt)*

Lead Authors:
Margaret CAMILLERI-FENECH *(Malta)*, **Mita DRIUS** *(Italy)*,
Francesca SPAGNUOLO *(Italy)*

This document should be cited as:
Moncada, S., Djoundourian, S., Kholeif, S., Camilleri Fenech, M., Drius, M., Spagnuolo, F., 2024: Sustainable Development Pathways. In: *Climate and Environmental Coastal Risks in the Mediterranean.* [Djoundourian, S., Lionello, P., Llasat, M.C., Guiot, J., Cramer, W., Driouech, F., Gattacceca, J.C., Marini, K. (eds.)]. MedECC Reports. MedECC Secretariat, Marseille, France, pp. 253-295, doi: 10.5281/zenodo.13753895

5

Chapter 5

Sustainable development pathways

Executive Summary

The attainment of climate-resilient development (CRD) pathways in the coastal areas of the Mediterranean remains a serious challenge. The pursuit of such pathways requires the proper identification of vulnerabilities related to human activities as well as climate change impacts, the assessment of opportunities to reduce risks to the affected communities, and the adoption of actions that are consistent with the Sustainable Development Goals (SDGs). The SDGs aim to shape most of the world's major priorities for improved livelihoods. Transformative actions are increasingly urgent across all sectors, systems, and scales to avoid exacerbating climate change risks and to meet the SDG's goals *(high confidence).* In climate-resilient development pathways, transformative actions involve leveraging change in key pillars of development that drive societal choices. Climate actions toward sustainability, such as social cohesion and equity, individual, collective and agency empowerment, and knowledge development, have been identified as crucial steps to transform practices and governance systems for increased resilience *(high confidence).* The efforts made by Mediterranean countries to adopt effective mitigation and adaptation measures are still insufficient to promote desirable and liveable futures, and to increase well-being for all Mediterranean coastal residents *(medium confidence).* Greenhouse gas emissions (GHG) in northern Mediterranean countries (NMCs) have been systematically decreasing since 2005, whereas in southern and eastern Mediterranean Countries (SEMCs), they have been increasing continuously since the 1960s *(high confidence).* Economic and population growth, especially in SEMCs, combined with increased demand for the electrification of transportation fleets, are the main factors for the observed rise in net emissions in the Mediterranean region, which has not yet managed to comprehensively decouple economic development from rising GHG emissions *(high confidence).* The most vulnerable actors of society, such as the elderly, migrants, women, children and low-income earners, who are often more at risk, are not necessarily at the centre of policy measures that aim for an efficient and just transition to a changed environment and climate *(medium confidence).* Despite some progress in promoting a sustainable energy transition that shifts away from fossil fuels towards renewable and clean energy sources, including solar energy, as well as efforts to support conservation and restoration of blue carbon pools such as coastal ecosystems, sustainable development pathways are not occurring at a sufficiently fast pace, thus increasing risks and the intensity of climate change impacts *(high confidence).* Marine renewable energy sources including offshore wind, wave, tidal current and thermal gradient energies are still in the early stages of development in the Mediterranean Sea, with only wind energy currently representing a feasible viable option *(medium confidence).* More importantly, further research is needed to establish the net impact of renewable energy sources on the unique biodiversity of Mediterranean coastal ecosystems *(medium confidence).*

Crucial socioeconomic sectors such as tourism, construction and real estate continue to be largely based on linear and extractive models of development, insufficiently embracing circularity and sustainable development practices *(medium confidence).* A mix of legal, policy, and economic instruments, and behavioural nudges, participation and bottom-up collaborations with citizens, can be used more extensively by local, national and regional authorities to promote effective climate resilient development pathways in the Mediterranean Basin, thus addressing environmental and climate change risks.

5.1 Introduction

5.1.1 Definitions and context

This chapter builds on the previous parts of the report, assessing challenges and opportunities to operationalise sustainable development trajectories. The concept of sustainable development has spread significantly since the early 1980s to become a core element of many policy documents adopted by governments, international agencies and business organisations (Mebratu 1998). Consolidated in 1987 by the much-acclaimed Brundtland report, the term stressed that humanity has the ability to make development sustainable through efforts to ensure that it meets the needs of the present without compromising the ability of future generations (WCED 1987). It also emphasised the need to impose limits on economic growth, especially in its excessive extractive and wasteful features, which are necessitated by the present state of technology and social organisation with regards to environmental resources, and by the limited ability of the biosphere to absorb the effects of current human activities. The report also brought to the forefront the three pillars of sustainable development, that is, economic, social and environmental factors while pointing out that 'what is needed now is a new era of economic growth — growth that is forceful and at the same time socially and environmentally sustainable' (WCED 1987, p.7).

The three pillars of sustainable development gained a dominant position within the literature, and consequently in key policy documents. The concept is often represented in Venn diagrams or nested concentric circles of the three main pillars, and while efforts to operationalise it has raised some uncertainties and lack of clarity (Purvis et al. 2019), the adoption of the Sustainable Development Goals (SDG) aims and targets contributes to improving the monitoring and evaluation of concrete actions to integrate the three dimensions of sustainable development within the UN system (UN 2012) and across various countries. The need to re-prioritise models of economic development trace back to the Club of Rome with the concept of limits to growth (Meadows et al. 1972), followed by Dasgupta and Heal (1980) who suggested the importance of including natural resources in economic modelling, and Johansson-Stenman, who highlighted the importance of incorporating ethics in environmental economic modelling (1998). In recent years, since the evolution of the concept of sustainable development, other approaches have emerged, such as well-being (Layard 2011), circular economy (Geissdoerfer et al. 2017), doughnut economics (Ross 2019), de-growth (Demaria et al. 2013), and *buen vivir* (Tolentino 2015), all with the aim of minimising the overall carbon footprint, fostering a harmonious relationship between nature and human activities, and a fairer distribution of resources and access to services among human populations. Nevertheless, sustainable development is still firmly enshrined as a global concept among the key trajectories for many international organisations, nation states and their official deliberations.

However, the shift to sustainable development is a complex and gradual process, and particular trajectories need to be actively pursued. These are referred to as sustainable development pathways. The definition adopted in this chapter for these pathways aligns with that adopted in the IPCC AR6 Report (IPCC 2022b). It refers to trajectories that involve 'transitions aligned with a shared aspiration in the SDGs', with 'efforts to eradicate poverty and reduce inequalities while promoting fair and cross-scalar adaptation to and resilience in a changing climate' (IPCC 2022a). These pathways involve the ethics, equity, and feasibility aspects of societal transformations, based on an array of social, economic, cultural, technological, institutional, and biophysical features that characterise the interactions between human and natural systems, with the aim of drastically reducing emissions to limit global warming, while achieving a desirable and liveable future and well-being for all (IPCC 2022a). The pursuit of climate-resilient pathways involves identifying vulnerabilities to climate change impacts, assessing opportunities for reducing risks, and taking actions that are consistent with the SDGs. The SDGs aim to shape most of the world's major priorities for livelihoods. The objectives embedded in the SDGs were ambitious and wide, ranging from the elimination of extreme poverty to major reductions in inequality and switching course to the protection of nature. Ambitious climate policies, as well as economic development, education, technological progress

and less resource-intensive lifestyles, are crucial elements for progress towards the main aims of the SDGs (Soergel et al. 2021). The clean energy share in industry (SDG 7) and air pollution concentration in cities (SDG 11) show positive trends and synergies with climate policies. Most development indicators (SDG 1, SDG 7) are closely associated with environmental indicators and exhibit trade-offs with climate policies (SDG 13), largely driven by higher energy and food prices (Soergel et al. 2021). Country size and sovereignty can also play a role in the capacity of countries to achieve SDGs (Moncada and Randall 2022).

Climate change, coupled with other global change drivers (pollution, urbanisation, rural exodus, population growth), is a growing threat for vital ecosystem services located in Mediterranean marine and coastal ecosystems *(high confidence).* In this chapter, the specific context targeted is the Mediterranean Basin, especially coastal areas and their communities, with the aim of identifying and assessing sustainable development pathways, including barriers to achieve them.

5.1.2 Layout of the chapter

Following this introduction, the chapter will first discuss the regional contributions and responses to climate stress and uncertainty in the Mediterranean Basin, looking at greenhouse gas (GHG) emissions and the current status of Nationally Determined Contributions (NDCs) plans for the countries in the Mediterranean region. Section three discusses the sustainable pathways in the context of the SDGs, while section four focuses on the specific topics of social and climate justice, including climate finance. Section five provides a conclusion.

5.2 Climate change response and related stress in the Mediterranean

GHG emissions are considered the overarching driver of climate induced changes that contribute to local coastal risks and hazards, including sea level rise, flooding, ocean acidification, etc. *(high confidence)* (see *Chapter 2*). This section highlights the regional contributions to global GHG emissions; identifies the mitigation and adaptation measures that individual governments in the Mediterranean Basin communicated in their initial and subsequent NDCs, in addition to other publicly documented measures, to combat climate change in support of SDG 13. It also evaluates the benefits and co-benefits of such measures and finally, determines the extent of the support that these measures provide towards achieving the SDGs.

5.2.1 GHG Emissions in the Mediterranean: a short summary

Over the past 50 years, the distribution of energy consumption within the Mediterranean region has changed dramatically. Energy consumption has increased steadily with figures shifting from 26 exajoules (EJ) in 1980 to 34 EJ in 1995 to 43 EJ in 2016. This represents an annual growth rate of 1.7%. Apart from a small decline in the use of coal, this positive trend accounts for oil, gas, nuclear, and renewables (Drobinski et al. 2020). Variations also exist within the Mediterranean Region. During the early 1970s, North Africa consumed only 4% of the total energy generated, whereas the European countries consumed 81%. By 2016, North Africa's share had increased to 19% while that of the Mediterranean countries within the European Union (EU) decreased to 59%. During the same period, per capita consumption in the Middle East and North Africa also increased relative to Europe, although the gap remains very wide. Türkiye, as a developing country required to fulfil its needs for development, also registered a significant increase in the consumption of fossil fuels and CO_2 emissions, starting in the 1990s (Bartoletto 2020; MedECC 2020a) *(high confidence)*.

By the year 2000, 72% of the GHG emissions consisted of CO_2 originating from energy use — 77% originating from Northern Mediterranean Countries (NMCs) and 64% from the Southern and Eastern Mediterranean Countries (SEMCs).[64] Historically, the growth of CO_2 emissions has been far more rapid in the SEMCs than in the NMCs. Whereas the NMCs reported an increase of 18% (mainly due to the transport sector) between 1990 and 2004, the emissions of the SEMCs increased by 58% over the same period (mainly due to electricity and heating). This growth rate is twenty points higher than the world average rate (European Investment Bank 2008), highlighting potential negative impacts for environmental and climate risks *(medium confidence).*

Despite this, the current share of carbon emissions of the Mediterranean countries accounts for no more than 6% of global emissions (FAO and Plan Bleu 2018), with NMCs contributing the larger proportion. The 2020 report on the State of the Environment and Development in the Mediterranean notes that emissions in NMCs reached their peak in 2005 but have since decreased. On the other hand, in SEMCs, CO_2 emissions have been increasing continuously since the 1960s. In 2014, the two regions were responsible for 1Gt of CO_2 emissions (UNEP/MAP and Plan Bleu 2020) *(high confidence).* This clashes with the requirements of the Paris Agreement, which necessitates that net CO_2 emissions decline significantly. However, according to current and future GHG emission projections, trends do not show a promising path towards their reduction (Ali et al. 2022). This is likely to be the result of the intermediate economic development of SEMCs, together with the final stages of democratic transition, which brought changes in the working population, shifting consumption patterns and resulting in an increase in energy, infrastructure and housing demand (European Investment Bank 2008). Energy demand, especially, is expected to continue its upward trend in the next few decades

---

[64] The Northern Mediterranean Countries (NMCs) gather twelve countries or entities: Croatia, Cyprus, France, Greece, Italy, Monaco, Montenegro, Malta, Slovenia, Spain. The Southern and Eastern Mediterranean Countries (SEMCs) gather ten countries or entities: Algeria, Egypt, Israel, Lebanon, Libya, Morocco, Palestine, Syria, Tunisia, and Türkiye.

(Plan Bleu and EIB 2008) given the expected growth in the population and economies of the southern Mediterranean Region (Ben Jannet Allal et al. 2016), but also in view of the electrification of fleets, which is not being accompanied by the same level of supply of renewable energy production (Milovanoff et al. 2020) *(high confidence).*

The 2019 inventory of net GHG emissions *(Table 5.1)* indicates that NMCs emitted a total of 1.2 million kt CO_2 equivalent, accounting for 11% of the total reported by Annex I[65] countries during this year. While Annex I countries report a decline of 18.94% in net emissions between the base year (1990) and the latest inventory (2019), the Mediterranean Basin countries in Annex I report an increase of 10.26% during the same period, attributed mainly to Türkiye's 158% increase in emissions.[66]

Table 5.1 shows the CO_2 equivalent emissions according to the 2019 inventory for Annex I and Non-Annex I countries. The percentage change of emissions from the indicated base year for every country is in columns 4 and 5. As can be noted, the three Balkan countries — Bosnia and Herzegovina, Croatia, and Montenegro — all registered a substantial decrease, while Egypt and Morocco registered a substantial increase in emissions. Increases were also recorded by Cyprus, Israel, Lebanon, Syria, and Tunisia. No figures are shown for Libya (no entry) and the State of Palestine has an entry limited to the single year 2011. Between 1990 and 2019, GHG emissions from these countries registered a net increase of 391.49% (UNFCCC 2023).

Total emissions in the Annex I Mediterranean countries (1.65kt of CO_2 equivalent), listed in *Table 5.1*, are higher than those of Non-Annex I Mediterranean countries (0.75kt of CO_2 equivalent). However, the increased efficiency in reducing emissions in the NMCs resulted in a much less drastic increase in total emissions in the region. In fact, between 1990 and 2019 the net increase in emissions was 72.18%. *(high confidence).*

In general, in the Annex I countries (eight European Mediterranean countries plus Türkiye), listed in *Table 5.1,* emissions are much higher than those of Non-Annex I countries. Türkiye has been recently included in Annex I because it has registered a significant increase in the consumption of fossil fuels and CO_2 emissions, starting in the 1990s *(high confidence).* However, the increased efficiency is mostly in the European Union Member States (EUMS), which resulted in a much less drastic increase in emissions. In fact, between 1990 and 2019, the net increase in emissions was 72.18% *(high confidence).* Therefore, the NMCs reported an increase of 18% between 1990 and 2004, while the emissions of the SEMCs increased by 58% over the same period. This growth rate is twenty points higher than the world average rate *(medium confidence).* This means that energy demand is expected to continue its upward trend in the next few decades given the expected growth in the population and economies and the electrification of fleets *(high confidence).*

---

[65] Parties to the UNFCCC are classified into three main groups according to differing commitments. Annex I countries refer to industrialised countries and economies in transition. Non-Annex I parties are mostly developing countries. In the Mediterranean, 14 countries are Non-Annex I countries, while the remaining nine countries are Annex I. https://unfccc.int/process/parties-non-party-stakeholders/parties-convention-and-observer-states

[66] Türkiye is an Annex I country but as stated in Decision 1/CP.16, Article 141, Türkiye's status and development needs are similar to those of Non-Annex I countries. https://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf

Table 5.1 | Changes in GHG Emissions in the Mediterranean. Source: GHG data from UNFCCC. https://unfccc.int/topics/mitigation/resources/registry-and-data/ghg-data-from-unfccc

Country	Party/Region	Base year/2019: net GHG Inventory (kt CO_2 equivalent)	Change in % (base year to 2019 inventory year)	Yearly average change in %
1. Albania	Non Annex I	**1990/2009:** 9,037	15.36	0.76
2. Algeria	Non Annex I	**1994/2000:** 103,143	2.79	0.46
3. Bosnia and Herzegovina	Non Annex I	**1990/2014:** 19,342	−27.34	−1.32
4. Croatia	Non Annex I	**1990/2019:** 18,048	−27.63	−1.11
5. Cyprus	Non Annex I	**1990/2019:** 8,457	58.02	1.59
6. Egypt	Non Annex I	**1990/2005:** 241,632	126.16	5.59
7. France	Annex I	**1990/2019:** 412,579	−21.49	−0.83
8. Greece	Annex I	**1990/2019:** 82,150	−18.81	−0.72
9. Israel	Non Annex I	**1996/2019:** 79,045	37.99	1.41
10. Jordan	Non Annex I	**1994/2016:** 31,037	68.96	2.41
11. Italy	Annex I	**1990/2019:** 376,719	−26.88	−1.07
12. Lebanon	Non Annex I	**1994/2013:** 22,766	43.10	1.90
13. Libya	Non Annex I	nil	nil	nil
14. Malta	Annex I	**1990/2019:** 2,175	−16.43	−0.62
15. Monaco	Annex I	**1990/2019:** 83,000	−19.59	−0.75
16. Montenegro	Non Annex I	**1990/2011:** 1,697	−58.33	−4.08
17. Morocco	Non Annex I	**1994/2012:** 100,545	152.10	5.27
18. Slovenia	Annex I	**1986/2019:** 16,964	8.66	0.25
19. Palestine	Non Annex I	Single entry (2011): 3,226	nil	nil
20. Portugal	Annex I	**1990/2019:** 59,617	−10.49	-0.90
21. Spain	Annex I	**1990/2019:** 276,952	9.03	0.30
22. Syria	Non Annex I	**1994/2005:** 79,216	50.07	3.76
23. Tunisia	Non Annex I	**1994/2000:** 32,096	37.35	5.43
24. Türkiye	Annex I	**1990/2019:** 422,085	157.69	3.32
Annex I	**Total**	**1990/2019:** 14,555,211	**−18.94**	**−0.72**
Non Annex I	**Total**	**na**	**na**	**na**

5.2.2 Mitigation efforts and the NDCs in the Mediterranean Basin

Mediterranean countries have the potential to mitigate climate change through energy transition and actions that include reduced use of fossil fuels and an increased adoption of renewable energy sources *(high confidence).* The implications of Russia's war in Ukraine brought up the issue of energy security into the forefront. Europe's strong dependence on energy supply from Russia is now forcing it to find alternative sources to maintain the security of supply in the region. Diversifying energy sourcing in addition to relying on renewable sources would be the key to energy security in the near future. This is especially relevant for all coastal areas, given their strategic location in terms of production and transportation of such renewable sources *(medium confidence).* According to the Organisation Méditerranéenne de l'Energie et du Climat (OMEC)[67], in 2030, even if all NDCs are reached, fossil fuels will still account for 71% of the energy mix in the region due to the inertia of transport and industry demand that cannot be hastily displaced. In a net-zero carbon future, renewables will need to step-up to reach 57% of the total energy mix by 2050 (OME 2022).

To reach carbon neutrality by 2050, energy demand in the NMCs will need to be reduced by a further 41%, whereas the increase in demand in the SEMCs should be capped at under 2% by 2050 from its current levels. Moreover, the fuel mix will need to be 57% renewables, 17% nuclear and 26% fossil (23% for gas alone — the least carbon intensive fossil fuel). At present, fossil fuels account for 76% of the energy mix (65% in the North and 92% in the South). This needs to decrease to less than 22%. Renewables, although fast increasing, stand at only 12% of the total Mediterranean energy demand and while that share reaches 15% in the North, it is barely attaining 8% of total energy demand in the South (OME 2022).

In the decades ahead, most capacity additions will need to stem from renewables and nearly all from solar and wind technologies. OME (2022) argues that the region needs to generate 600 GW of net additional capacity from solar energy and 500 GW from both onshore and offshore wind energy technologies by 2050.

Current solar capacity stands at 85 GW in the entire Mediterranean region (OME 2022). By the end of 2018, around 2.9 GW of solar photovoltaic (PV) were operating in the Middle East and North Africa, with 12 GW of solar PV projects under construction or awarded. The SEMCs have huge solar irradiation levels making them ideal for large-scale development of solar PV power. For example, while Algeria currently generates just 500 MW of PV power, its national plan for the development of renewable energy indicates that around 60% of new renewable energy power (around 13,575 MW) would originate from solar PV and 5010 MW from wind power (Ciriminna et al. 2019).

Marine renewable energy sources, while feasible for coastal areas in general, are still in the early stages of development in the Mediterranean Sea. Blue energy sources include the use of offshore wind, wave, tidal current and thermal gradient energies. The potential for using these sources of energy varies dramatically in the Mediterranean Basin, with wind energy being a suitable alternative, while wave energy is still a limited option (*low* to *medium confidence*). Numerous offshore wind projects are at a concept or early planning stage in the northern Mediterranean — notably in France, Greece, Italy, Spain, and Portugal. According to Soukissian et al. (2017), the Gulf of Lion and the Aegean Sea are the most favourable areas for offshore wind energy projects in terms of potential (with 1050 and 890 $W\ m^{-2}$, respectively) at 80 metres above the sea level. When bottom depth suitability is considered, additional candidate areas include the Adriatic Sea and the Gulf of Gabès. The first offshore wind farm was inaugurated in April 2022 off the coast of Italy with a total capacity of 30 megawatts (MW) and an estimated output of 58,000 megawatt-hours (MWh) per year, enough to power 21,000 homes. By 2028, two offshore wind parks are expected to be operational off the coast of Sicily,

---

[67] Formerly Observatoire Méditerranéen de l'Energie (OME).

with a total capacity of 750 MW, estimated to generate over 2000 GWh of electricity annually, equal to the average annual power demand of about 750,000 homes. Three pilot projects of floating offshore farms have been approved in the Gulf of Lion, France, and are due to be built before 2023 (Plan Bleu 2022c). In December 2021, Spain approved the Maritime Space Management Plans (Planes de Ordenación del Espacio Marítimo, or POEM) with plans to reach 3 GW by 2030, and an overall potential capacity of reaching 17 GW by 2050[68]. The European Wind Energy Association (EWEA)[69] projects that, by 2030, 150 GW could be produced using wind power in Europe's coastal waters; energy sufficient to service the electricity demands of 145 million households. Furthermore, by 2050, EWEA predicts that offshore wind could reach 460 GW, producing 1813 TWh of electricity, equivalent to 50% of the European electricity supply (Piante and Ody 2015). The Mediterranean Sea has a very low wave energy resource with the highest average wave power in the region being around 6 kW m^{-1}. Wave energy is more expensive than offshore wind energy and its technological development is far behind wind turbine technological developments. It is therefore expected that the development of wave energy will be slow and limited in the future. Tidal resources are currently limited to the Straits of Messina, Bosporus, and Gibraltar. The development of electricity based on tides and currents will remain limited in the future (Piante and Ody 2015). The information is summarised in *Table 5.2.*

Almost all countries (except Libya) in the Mediterranean Basin have committed through their initial NDCs or updated NDCs to reducing energy consumption and using renewable energy sources to reduce GHG emissions, by 2030.[70]

In North Africa, Morocco's renewable energy target of 52% stands out as the most ambitious plan in the region. Morocco committed to reducing its GHG emissions by 42%, with an unconditional[71] reduction target of 17% by 2030. Algeria committed to reducing energy consumption by 9% and deriving 27% of all electricity production from renewable sources. It aims to produce 27% of its electricity from renewable resources by 2035, the majority of which will originate from solar power. Tunisia declared its intentions to reduce its carbon intensity by 41% from 2010 levels and adopt renewable energy sources to power desalination plants in addition to using more efficient desalination techniques (OME 2022). Finally, Egypt committed to reducing its energy intensities and promoting low-carbon technologies in addition to decreasing all sources of emissions. In the NDCs which was updated in 2022, Egypt's mitigation targets include a 33% reduction in GHGs compared to a business-as-usual scenario in 2030. Furthermore, it plans to increase its commitment to renewable energy, while reducing coal capacity and replacing inefficient thermal power plants and promoting large and small-scale decentralised renewable energy systems.

The EU, in its initial and binding NDC, has targeted an economy-wide net reduction of at least 55% of GHG emissions from base year values, without contributions from international credits. Considering the implications of COVID-19 on its economy, a decision was made to deliver at least the reductions pledged in the EU's initial NDC. The efficiency of the EU's final and primary energy consumption will be improved by at least 32.5% by 2030 as compared to an historic baseline. A new target for increasing renewable energy in final energy consumption has been set to reach at least 32% by 2030 (Kulovesi and Oberthür 2020).

Elsewhere in Europe, the Principality of Monaco plans to achieve carbon neutrality by 2050. The pledge is to reduce its GHG emissions by 30% by 2020 and 80% by 2050, compared with the reference year of 1990. Albania intends to reduce CO_2 by only 11.5% by 2030 in the period between

---

[68] https://maritime-spatial-planning.ec.europa.eu/countries/spain

[69] The EWEA has rebranded to Wind Europe: https://windeurope.org

[70] In accordance with Article 4, paragraph 12 of the Paris Agreement (UNFCCC 2015), NDCs communicated by Parties shall be recorded in a public registry maintained by the UNFCCC secretariat. The registry can be accessed here: https://unfccc.int/NDCREG

[71] NDCs can be conditional or unconditional — whether or not they depend on international financing and support.

Table 5.2 | Current and future energy policies in the Mediterranean.

Current energy situation	Projected policies
76% originates from fossil fuel, 12% from renewables (OME 2022).	A significant energy transformation is required to reach carbon neutrality by 2050. The energy fuel mix must reach the following targets: 57% renewables, 17% nuclear, and 26% fossil (out of which 23% is gas) (OME 2022).
Wind energy is gaining popularity. For example, Italy inaugurated a farm with 30 MW that can power 21,000 homes (Plan Bleu 2022c).	More wind energy projects are planned. For example, by 2028, a 750 MW wind farm in Sicily, Italy, with the ability to power 750,000 homes. Similar plans are underway for the Gulf of Lion, France. By 2050, wind energy capacity could reach 460 GW (Plan Bleu 2022c).
The Mediterranean Sea does not provide a high wave energy resource. The highest average wave power within the region reaches 6 kW m^{-1} (Piante and Ody 2015).	Tidal energy potential is constrained due to limitations in wave power. It is still expensive, and technological developments are limited (Piante and Ody 2015).

2016 and 2030. This translates into a 708-tonne reduction of CO_2 emissions by 2030. The country plans to increase the share of renewable energy use (in gross final energy consumption) to 42% by 2030 (IRENA 2021a).[72] Bosnia and Herzegovina set an unconditional GHG emissions reduction target for 2030 of 33.2% and a conditional target (with more intensive international assistance for the decarbonisation of mining areas) of 36.8% relative to 1990 by 2030. The GHG emissions reduction target for 2050 is 61.7% (unconditional) and 65.6% (conditional) compared to 1990.[73] Finally, Montenegro committed to an economy-wide GHG emissions reduction target of 35% by 2030 compared to base year (1990) emissions, excluding Land Use, Land-Use Change and Forestry (LULUCF).[74]

In the Middle East, Türkiye's leading mitigation policies in the energy sector for 2030 include reaching 33 GW of solar, 18 GW of wind, 35 GW of hydroelectric, and 4.8 GW of nuclear-installed power capacity, and to increase renewable energy sources overall in primary energy consumption to 20.4% by 2030. Moreover, the plan intends to reduce losses from electricity transmission and distribution to 15% by 2030. Lebanon intends to reduce emissions and increase renewable energy use by 15% each and improve energy-efficiency levels by 3% by 2030, conditional on financing. Syria pledged to reduce dependence on fossil fuels and intends to increase renewable energy use to 10% by 2030. As per 2012, Syria had an installed renewable energy capacity of 0.84 MW of solar PV panels and 1505 MW of hydro power but

---

[72] Albania intends to sell carbon credits during the period until 2030 to contribute to cost-effective implementation of the low emission development pathway and its sustainable development.

[73] See also: https://climatepromise.undp.org/what-we-do/where-we-work/bosnia-and-herzegovina

[74] See also: https://climatepromise.undp.org/what-we-do/where-we-work/montenegro

projected to increase PV panels to 1750 MW and wind energy to 2000 MW by 2030. Other forms of renewable energy include the increase of biomass sources to 400 MW by 2030 (IRENA 2014).

Israel committed to an economy-wide unconditional target of reducing its emissions by 26% below 2005 levels, through energy efficiency (17% reduction in electricity consumption) and use of renewable energy (17% of the electricity generated) in 2030.[75] Furthermore, it committed to a 30% reduction of greenhouse gas emissions from electricity generation by 2030 and 85% by 2050 compared to emissions measured in 2015. The information is summarised in *Table 5.3.*

The transition to resilient energy efficient pathways requires a significant transformation of energy policies and economic models in Mediterranean countries (Feleki and Moussiopoulos 2021). While the NMCs have the resources and facilities to make the leap towards the transition, some of the SEMCs need support, knowledge transfer, funding and capacity-building programmes *(high confidence).*

5.2.3 Co-benefits and costs of mitigation and adaptation

Mitigation of and adaptation to environmental pollution and climate change impacts, while not without cost or residual damage, may substantially reduce the adverse risks, and/or enhance co-benefits to possibly spill over to societal well-being (Smit et al. 2001). According to Deng et al. (2017), the co-benefits from GHG mitigation that have received the most attention in the literature include impacts on ecosystems, economic activity, health, air pollution, and resource efficiency, whereas those receiving the least attention include impacts on conflict and disaster resilience, poverty alleviation (or exacerbation), energy security, technological spillovers and innovation, and food security.

Renewable energy sources, such as solar power and wind farms, while usually viewed as benign and sustainable alternatives to fossil fuels, may not be trouble free. The replacement rate of solar panels is faster than expected and given the current high recycling costs, there's a real danger that all used panels will go straight to landfill. The International Renewable Energy Agency predicts that 'large amounts of annual waste are anticipated by the early 2030s' and could total 78 million tonnes by the year 2050 (IRENA and IEA-PVPS 2018).

The construction of offshore wind farms may introduce or add pollutants (synthetic and non-synthetic compounds) to the sea. This is, in addition to the disruption it may cause during the construction phase. The environmental effects of offshore wind farms in the Mediterranean are poorly studied (Bray et al. 2016; Lloret et al. 2022) *(medium confidence).* Since the Mediterranean is a semi-closed sea with particular characteristics including minimal tidal ranges, high levels of biodiversity and endemism (Coll et al. 2010), and a high potential of non-indigenous species invasion (e.g. Kourantidou et al. 2021), the effects of existing offshore wind farms may not be directly applicable to the Mediterranean, highlighting the urgent need for site-specific analyses (Bray et al. 2016; Lloret et al. 2022) *(medium confidence).* In detail, the Mediterranean Sea hosts endemic seabird species for which there have yet to be any impact assessments. It is also a major and crucial transit route for Saharan-Eurasian bird migration, as evidenced by both the Mediterranean-Black Sea flyway and the Adriatic flyway (Bray et al. 2016) *(high confidence).* Wind farms affect resident and migrating birds, through avoidance behaviours, habitat displacement, and collision mortality (e.g. Dierschke et al., 2016). Considering marine mammals, both resident and visiting species, of which most are experiencing a decline in population trends, occur in the Mediterranean Sea. The principal negative impacts on marine mammals and fish populations caused by wind farms are noise and electro-magnetic fields. Although research has indicated that some species of seabirds strongly and consistently avoid offshore wind farms, thus minimising impacts and possible effects on the bird population, other species (mostly cormorant)

---

[75] https://www.gov.il/en/pages/reducing_greenhouse_gases_increasing_energy_efficiency

Table 5.3 | Commitments of selected Mediterranean countries to reduce GHG emissions. Source: UNFCCC 2023, https://unfccc.int/NDCREG.

Country	Targets	Additional comments
1. Albania[A]	↓ CO_2 by 11.5% by 2030 compared to the baseline scenario starting in 2016. This amounts to a 708 kt reduction of CO_2 emissions.	Fossil fuels, mainly crude oil, generate between 46 and 68% of energy while hydropower is the largest energy contributor with a share ranging between 20 and almost 40% (depending on the annual rainfall). The country is endowed with abundant renewable energy potential.
2. Algeria[B]	↓ Energy consumption by 9% by 2030 while 27% of energy is derived from renewable sources.	Strategic partnerships are being sought by the government in the field of renewable energy with multiple countries including foreign suppliers of technological services.
3. Bosnia and Herzegovina[C]	↓ GHG emissions by 12.8% relative to 2014 (unconditional) and 33.2% relative to 1990 (conditional) by 2030.	Plans to install mini hydro power plants, wind farms, and photovoltaic modules with a total energy generation capacity of 120 MW, 175 MW, and 4 MW respectively, by 2030.
4. Croatia[D]	↑ Share of renewable energy to 36.4% by 2030.	Forms part of the EU binding[e] climate and energy target for 2030 to reduce GHG emissions by at least 40%, increase energy efficiency by 32.5%, increase the share of renewable energy to at least 32% of EU energy and guarantee at least 15% electricity interconnection levels between neighbouring countries.
5. Cyprus[F]	↓ Emissions in sectors not covered by the EU Emissions Trading System (non-EU ETS) by 24% compared to 2005. Renewable energy share is set at 19% of gross final energy consumption of energy in 2030.	Forms part of the EU binding climate and energy target.[E]
6. Egypt[G]	↓ Emissions by 33% in the electricity sector, 65% in the oil and gas sector, and 7% in the transportation sector by 2030.	Installation of renewable energy to generate 42% of electricity by 2035.
7. France[H]	↓ GHG emissions by 36% by 2030. Aims to be carbon neutral by 2050.	Forms part of the EU binding climate and energy target.[E]
8. Greece[I]	↓ Non-EU ETS emissions by 14% compared to 2005 ↑ The share of renewable energy to 31% by 2030.	Forms part of the EU binding climate and energy target.[E]

[A] See also: https://climatepromise.undp.org/what-we-do/where-we-work/montenegro

[B] See also: OME 2022

[C] See also: IRENA 2023

[D] See also: https://energy.ec.europa.eu/system/files/2019-06/necp_factsheet_hr_final_0.pdf

[E] See also: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2030-climate-targets_en

[F] See also: https://energy.ec.europa.eu/system/files/2019-06/necp_factsheet_cy_final_0.pdf

[G] See also: https://climatepromise.undp.org/what-we-do/where-we-work/egypt

[H] See also: https://energy.ec.europa.eu/system/files/2019-06/necp_factsheet_fr_final_0.pdf

[I] See also: https://energy.ec.europa.eu/system/files/2019-06/necp_factsheet_el_final_0.pdf

Country	Targets	Additional comments
9. Italy[J]	↓ GHG emissions by 33% by 2030.	Forms part of the EU binding climate and energy target.[E]
10. Israël[K]	↓ GHG emissions by 26% below the 2005 emissions level by 2030.	To be achieved by improving energy efficiency (17% reduction in electricity consumption) and use of renewable energy (17% of the electricity generated) by 2030.
11. Jordan	↓ GHG emissions by 31% by 2030 as compared to BAU scenario in 2012.	Renewable energy to contribute by 35% by 2030 and improve energy efficient consumption by 9% in all sectors.
12. Lebanon	↓ unconditional and conditional GHG emissions by 20 and 31% compared to 2012 BAU scenario in 2030. ↑ use of renewable energy by 15%.	Improve energy-efficiency levels by 3%.
13. Libya[L]	n/a	Signed the UNFCCC agreement in 2015 but no requisite policies were submitted.
14. Monaco[M]	Carbon neutrality by 2050.	Reduce GHG emissions by 30% by 2020 and 80% by 2050, compared to base year.
15. Montenegro[N]	↓ 35% of GHG emissions by 2030.	UNDP notes that the revised NDC does not specify the adaptation measures.
16. Morocco	↓ 45% GHG emissions by 2030 ↑ 52% of ts installed electricity capacity from renewable sources by 2030.	17% to be unconditionally reduced by 2030.
17. Palestine (State of)	↓ GHG emissions by 26% by 2040 (conditional).	Improve energy efficiency by 20% (business as usual) across all sectors by 2035.
18. Portugal	↓ GHG emissions by 17% as compared to 2005. ↑ Renewable energy to 42% of national gross consumption of energy.	Forms part of the EU binding climate and energy target.[E]
19. Slovenia[O]	↓ GHG emissions by 15% as compared to 2005.	Forms part of the EU binding climate and energy target.[E]
20. Spain[P]	↓ GHG emissions by 26% compared to 2005 levels. ↑ Energy from renewable sources to 35% by 2030.	Forms part of the EU binding climate and energy target.[E]

[E] See also: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2030-climate-targets_en

[J] See also: https://energy.ec.europa.eu/system/files/2019-06/necp_factsheet_it_final_0.pdf

[K] https://www.gov.il/en/pages/reducing_greenhouse_gases_increasing_energy_efficiency

[L] See also: https://www.undp.org/libya/environment-and-climate-change

[M] See also: https://en.gouv.mc/Policy-Practice/The-Environment/The-Climate-and-Energy-Plan-in-the-town

[N] See also: https://climatepromise.undp.org/what-we-do/where-we-work/bosnia-and-herzegovina

[O] See also: https://energy.ec.europa.eu/system/files/2019-06/necp_factsheet_si_final_0.pdf

[P] See also: https://energy.ec.europa.eu/system/files/2019-06/necp_factsheet_es_final_0.pdf

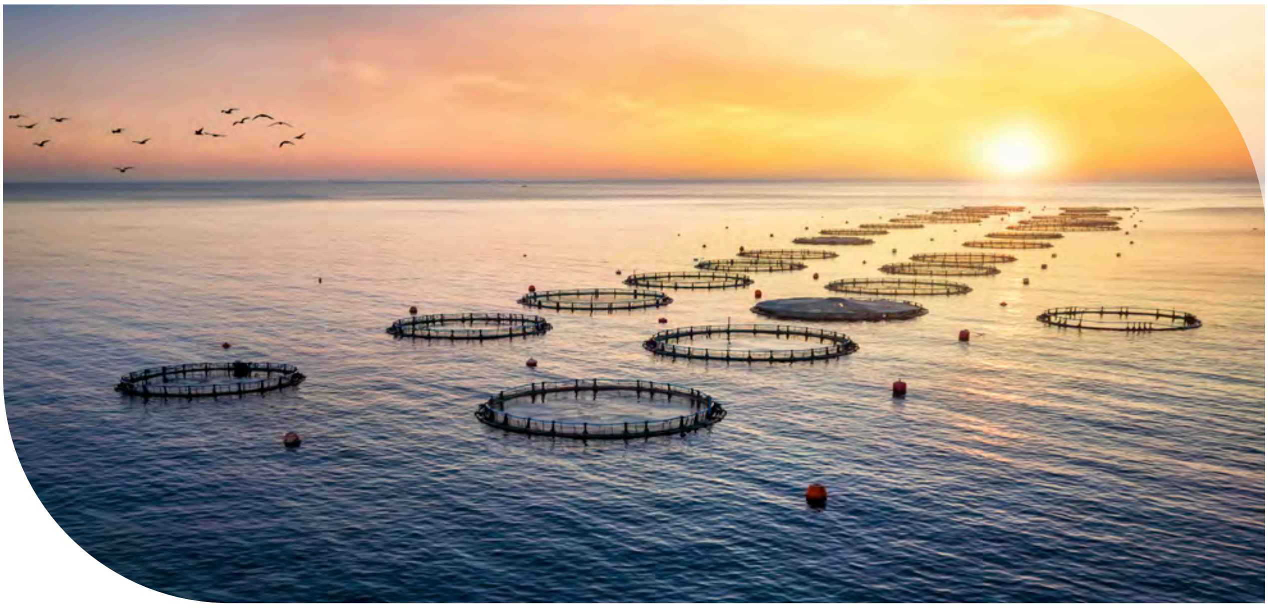
Country	Targets	Additional comments
21. Syria[Q]	↓ Dependence on fossil fuels. ↑ Renewable energy use to 10% by 2030.	Renewable energy target focused on PV panels, wind and biomass.
22. Tunisia	↓ GHG emissions by 41% below 2010 levels by 2030 (27% unconditional).	Modernise desalination plants with renewable energy.
23. Türkiye	↓ GHG emissions by 41% by 2030 compared to BAU scenario. This is double the previous target of 21%.	10 GW derived from solar power, 16 GW from wind power, the remaining from nuclear and hydroelectric power. Reduce losses from electricity transmission and distribution to 15% by 2030.

tend to be more negatively impacted by such wind farms (Dierschke et al. 2016), calling for further investigation in the Mediterranean (Bray et al. 2016; Lloret et al. 2022) *(medium confidence).* Some studies argue that offshore wind farms could be beneficial for benthic habitats and animals, because they offer an artificial reef that may provide space for settlement, shelter and foraging (e.g. Mavraki et al. 2020). This apparent benefit should be carefully assessed in the case of the Mediterranean Sea, due to its high habitat heterogeneity. On the one side, long-term effects of ecosystem shifts are unknown; on the other side, the creation of new and artificial substrates favours colonisation by opportunistic species and the arrival of non-indigenous species that can alter the local biodiversity balance (Lloret et al. 2022) *(medium confidence).* All this considered, systematic scientific information on the risk of each potential interaction between offshore wind farms and different ecosystem elements is needed to inform managers and decision-makers during offshore wind farm planning in order to minimise adverse effects and adopt mitigation measures (Galparsoro et al. 2022) *(high confidence).*

While mitigation efforts are important, enhancement of adaptive capacity is a necessary condition for reducing vulnerability, especially for the most vulnerable regions and socio-economic groups. Activities that usually improve adaptive capacity also promote sustainable development *(high confidence).* In coastal zones, improving adaptive capacity may require a wide array of measures including planting salt-tolerant varieties of vegetation, establishing agricultural practices that are more resistant to flooding (Maggio et al. 2011), developing desalination techniques, establishing mechanisms for disaster response, and empowering communities to build resilience to extreme events (Iglesias et al. 2018), etc.

Pollution reduction (mainly water pollution from wastewater and urban runoff) improves human health (waterborne diseases, food poisoning from chemical discharges and contaminated fish consumption) (Analitis et al. 2008), development of sustainable energy systems for both use in industrial production and consumption (renewable energy production and use) (Pisacane et al. 2018; Kougias et al. 2019), employing less-intensive industrial fishing practices (Giordano et al. 2019), although these must be appropriately regulated for environmental recovery programmes in order to be effective and not damage marine ecosystems (Enrichetti et al. 2019) *(high confidence).* Maritime emissions from ships (especially sulfur oxides (Sox), particulate matter (PM), nitrogen Oxides (Nox)) in the Mediterranean Sea area are a serious threat to public health and the economy. Action to address these risks by reducing maritime emissions can yield health benefits that outweigh the costs to the maritime shipping sector by a wide margin (on average, by a factor of 7 in 2030 and by a factor of 12 in 2050; Cofala et al. 2018), especially when also taking into account the co-benefits of various climate policies.

[Q] See also: IRENA 2014



Mitigation and adaptation efforts will potentially affect the availability and prices of energy, food (fisheries, aquaculture), and other ecosystem-intensive services (tourism) (*medium* to *high confidence*). Sustainable development pathways will require social mobilisation and necessary investments in capacity-building to avoid exclusion, and protection of the interests and rights of people vulnerable to the impacts of climate change and of future generations (UNEP 2019).

Boyd et al. (2022) argue that the alignment of adaptation and development goals is a more common aim than the alignment of adaptation and mitigation. They therefore advocate creating incentives to meet multiple policy priorities, reduce costs, and increase resource efficiency and institute co-benefit approaches that cover adaptation, mitigation, and development goals.

Although climate change adaptation has been identified as an essential policy response (Eriksen et al. 2011), it has received less attention when compared to mitigation in terms of legislative and funding initiatives (Sietsma et al. 2021). In the Mediterranean region, especially in its coastal areas, climate change adaptation can play a central role to support the resilience of ecosystems to climate risks (Aurelle et al. 2022). Furthermore, the vast traditional ecological knowledge heritage present in the Mediterranean can be used for adaptation, promoting for instance, more agroforestry practices that would improve livelihoods while adapting to climate change (Aguilera et al. 2020) *(high confidence)*. Within the combination of solutions to foster climate change adaptation there is also the prevention, or removal of settlements, infrastructure and assets in areas affected by SLR/erosion/storms, which can reduce risks in the first place, but also be a more cost-effective solution in the long-term (Siders et al. 2021) *(medium confidence)*. As such, the long-term, potentially transformative option of managed retreat must be considered for some areas and for specific sectors, including agriculture (Fraga et al. 2020) *(medium confidence)*. This can indeed be challenging in regions where inland areas face desertification and other compound risks (wildfires, floods, etc.) but with the appropriate planning can be a sustainable solution (Siders et al. 2021) *(medium confidence)*.

While it is relevant to understand the relative importance of different kinds of actions (mitigation and adaptation), it also essential to understand the potential positive and negative synergies between them. A proper assessment of outcomes would require that policymakers conduct a cost-benefit analysis complemented by an analysis of distributional effects to prioritise adaptation programmes as well as other development programmes to promote an efficient and just transition to climate change (Bellon and Massetti 2022) *(high confidence)*.

Box 5.1

Capacity-building and knowledge transfer for sustainable development

Capacity-building is an essential catalyst to sustainable development and human welfare on the planet and is essential for enabling all countries to benefit from all-natural resources and conserve their future. Capacity-Building is an important part of the means to implement the Sustainable Development Goals (UN General Assembly 2015, para. 41). Each of the SDGs contains targets related to the means of implementation, including capacity-building. For example, SDG 17, which covers the means of implementation and the global partnership for sustainable development, contains Goal 17.9 which aims to strengthen international support for the implementation of effective and targeted capacity-building in developing countries to support national plans to implement all development goals, including through North-South cooperation, South-South cooperation and triangular cooperation.

What does capacity-building mean? How best to define it?

Capacity-building (or capacity development, or capacity strengthening) is the improvement of an individual, organisation, or country's ability to produce, perform, or deploy. The terms capacity-building and capacity development are often used interchangeably. The Organisation for Economic Co-operation and Development (OECD) stated that capacity development is the preferred term (OECD-DAC 2006).

The general definition of capacity development is as follows: 'Capacity development is a transformative approach that enables individuals, leaders, organisations and societies to acquire, strengthen and maintain capabilities to set and achieve their own development goals over time.' Simply put, if capacity is the means to plan and accomplish, then capacity development describes the methods of those means. Capacity development refers not only to the acquisition of new knowledge and skills, but also above all to the change of values and behavioural patterns (UNDP 2015).

Capacity-building is one of the boundless terms most often used to describe the distance between developed and developing countries. It is very rich and complex and is undoubtedly a prerequisite for saving our planet. However, it is usually underestimated and implemented in an inefficient and traditional 'business-as-usual' scenario.

Historical context

Capacity-building has long been recognised as one of the means of implementation for achieving sustainable development action plans and development strategies. Agenda 21, adopted at the 1992 United Nations Conference on Environment and Development[76], addresses capacity-building in its Chapter 37 (UN 1992). Decisions relating to capacity-building were taken by the United Nations Commission on Sustainable Development at its fourth (1996), fifth (1997) and sixth (1998) sessions and by the United Nations General Assembly at its Special Session to review the implementation of Agenda 21[77] (1997).

The Johannesburg Plan of Implementation (JPOI), adopted at the 2002 World Summit on Sustainable Development[78] also recognised the importance of capacity-building for the achievement of sustainable development. Similarly, the outcome document of the Rio +20 Conference, the Future We Want, emphasised the need for enhanced capacity-building for sustainable development and for strengthening technical and scientific cooperation (UN 2012). Capacity development is also recognised as a key issue in the 2014 SAMOA Pathway[79] for a wide range of areas, such as climate change, sustainable energy, ocean sustainability, management of chemicals and waste, as well as financing.

UNDP integrates this capacity-building system into its work on achieving the Millennium Development Goals (MDGs). It focuses on building capacity at the institutional level because it believes that 'institutions are at the heart of human development, and that when they are able to perform better, sustain that performance over time, and manage 'shocks' to the system, they can contribute more meaningfully to the achievement of national human development goals.' (UNDP 2015).

In the context of restoration and conservation of the world's oceans and coasts; the UN Ocean Decade for sustainable Development (2021–2030) Implementation Plan (IP) recognises capacity development as an essential tenet to achieving evenly distributed capacity across the

---

[76] https://www.un.org/en/conferences/environment/rio1992

[77] https://www.un.org/en/conferences/environment/newyork1997

[78] https://www.un.org/en/conferences/environment/johannesburg2002

[79] https://www.un.org/ohrlls/content/samoa-pathway

Box 5.1

globe, across generations, and across genders and thus reversing asymmetry in knowledge, skills and access to technology (UNESCO-IOC 2021).

Capacity-building as a transformative system for the world's climate-environment risk management

One of the most pressing challenges in the world is coastal urbanisation, impacting the well-being of ecosystems, with climate change exacerbating this process, thus the need for advanced knowledge and capacities to deal with coastal inundation, coastal pollution, and multi-hazards. Ocean acidification and climate change caused by ocean absorption of anthropogenic carbon dioxide from the atmosphere, and acidification of ocean surface waters, mostly due to carbon dioxide emissions, can severely threaten the existence of various marine species. Since the mid-19th century, sea level has risen as a result of human-induced climate change. A number of coastal cities and coastal resources are becoming heavily impacted by sea level change.

Within the Mediterranean Sea, national, regional, and international entities have launched many effective initiatives for global coastal observation, prediction, and scientific capacity development for the decade. However, beyond scientific capacity development, it is crucial to create new awareness at the policy and civil society level, identify alternative solutions, reduce fragmentation, and facilitate cooperation between countries. The effective use of unprecedented achievements in capacity development, is indispensable to ensuring that growing development demands, and a sustainable healthy ocean coexist in harmony.

5.3 Sustainable pathways and significant targets across SDGs

This section briefly introduces the SDGs and discusses current efforts to achieve their targets, including a focus on sustainability pathways in the Mediterranean Basin. It also highlights the impacts of sustainability measures on a range of different sectors, especially those that most significantly impact climate change in the context of coastal communities. It will continue by discussing short-term (2021–2040), versus medium-term (2041–2060) and long-term (2061–2100) efforts to achieve sustainability pathways and how the trade-offs between different SDG targets can potentially lead to favourable transition for new sustainable pathways. This section will also discuss how policies, data, technology and communication can act as catalysts for effective and long-lasting development pathways.

In 2015, 17 SDGs were adopted by all UN member states. Also known as Global Goals, the SDGs aim to provide a universal call to end poverty, protect the planet and ensure that by 2030 all people are on the path to enjoy peace and prosperity. Each SDG has a set of indicators, some of which are multipurpose and are used to monitor more than one SDG, and more than one of the three pillars of sustainable development.

For the first time since the adoption of the SDGs, the average score for the 2020 Global Sustainable Development Goals Index has fallen from the previous year, affecting all three dimensions of sustainability. The COVID-19 pandemic, a growing population, and other crises have clearly been major setbacks for attaining sustainable development (Sachs et al. 2020). In 2021, the negative impacts brought by the COVID-19 pandemic, especially in the area of reduced connectivity and economic activities, continued to be a major factor contributing to high rates of poverty and unemployment, which prompted an overall decline in the performance of the sustainable development goals at the global level (Shulla et al. 2021). The economic and financial shocks associated with COVID-19 also impacted the funding for sustainability, making it more difficult and undermining the general approach toward achieving the 17 SDGs by the established 2030 deadlines, therefore slowing down the set trajectory of development (*medium* to *high confidence*). The overarching aim of 'leave no one behind' is threatened by the current growing inequalities (Shulla et al. 2021). A lack of resources, especially in funding, ought to prompt a need for interdisciplinary thinking systems, allowing key policies, such as trade and technological innovation, to support the attainment of the sustainable development goals (Sachs et al. 2022).

Mediterranean countries have the potential to mitigate climate change and contribute to the achievement of other SDGs through the proper conservation and restoration of blue carbon ecosystems such as coastal wetlands (e.g. coastal lagoons, seagrass meadows and salt marshes; see for instance Eid et al. 2017), but also of coastal terrestrial ecosystems (Filho et al. 2020), including coastal dunes (Drius et al. 2019). These coastal ecosystems are important and contribute to the well-being of people and nature by providing good-quality water, acting as a barrier to the negative effects of extreme climate events, contributing to food production, and by preserving biodiversity (Spalding et al. 2014; Aurelle et al. 2022). The carbon sequestration capacity of coastal wetlands is about 10 times that of terrestrial ecosystems (Mcleod et al. 2011). *Posidonia oceanica,* endemic to the Mediterranean Sea and sometimes referred to as 'the lungs of the Mediterranean', is the most widespread seagrass species in these waters *(high confidence).* It has a significant role as a carbon sink, absorbing carbon dioxide, storing carbon at an average rate of 83g C m^{-2} per year, and helping to alleviate the effects of climate change. It covers between 25,000 and 50,000 km^2 of coastal areas, corresponding to 25% of the sea bottom at depths of 0 to 40 m. As a co-benefit, the high levels of primary production contribute to the oxygenation of the water column (Koopmans et al. 2020; Hendriks et al. 2022). The *Posidonia* population, listed on the IUCN Red List of Threatened species[80], has been declining at the rate of approximately 10% over the last 100 years, with recent estimates of over 30% in the past 50 years, in many parts of the Mediterranean, due to pollution, coastal development, fishing activities, the mooring of ships (Boudouresque et al. 2009; Telesca et al. 2015), and climate change (Chefaoui et al. 2018). Proper valuation and pricing of Mediterranean blue carbon ecosystems that primarily include seagrasses and salt marshes could allow conservation and restoration initiatives that may foster sustainable development (Bertram et al. 2021).

Mediterranean countries do not seem to be on the right track to achieve most of the SDGs (Sachs et al. 2022). They appear to be performing well for some of the SDGs, such as eradicating poverty (SDG 1), promoting good health and well-being (SDG 3), and quality education (SDG 4). However, they score poorly and underperform quite alarmingly in areas such as biodiversity protection, including life underwater (SDG 14) and life on land (SDG 15), and climate change (SDG 13); social integration, including gender equality (SDG 5) and reduced inequalities (SDG 10). The Mediterranean region is the second most vulnerable to climate change after the Arctic (MedECC 2020a), broadly connected to political, economic, social and environmental imbalances, also exacerbated by differences across geographical regions, which can grow even bigger due to the negative impacts of climate change in the region. Current regional and cross-country partnerships can favour the uptake of sustainable development initiatives in the Mediterranean, including measures supported by the EU, the Union for the Mediterranean (UfM), the United Nations Environmental / Programme Mediterranean Action Plan (UNEP/MAP), among others, in the spirit of SDG 17 (Partnership for the goals), to foster sustainable pathways. There is *robust evidence* that current development pathways are leading away from sustainable development (IPCC 2022b; Schipper et al. 2022) *(high confidence).*

5.3.1 Determining the pathways to sustainability for major sectors

It is well known that climate change impacts reduce the ability of countries to achieve sustainable development (UN General Assembly 2015) and that these impacts can take away improvements in living conditions and decades of progress on development pathways. For instance, dangerous levels of climate change are likely to limit efforts in reducing poverty, as its negative impacts are more severely felt by low-income and vulnerable people, especially because of their high dependence on natural resources, which are becoming scarcer and less accessible, and the

---

[80] https://www.iucnredlist.org/species/153534/135156882

limited capacity of low-income and vulnerable groups to properly cope with climate variability and extremes (Hallegatte and Rozenberg 2017) *(high confidence).*

The adoption of the Paris Agreement and the 2030 Agenda demonstrated a growing international consensus to pursue the fight against climate change as a key component of the broader objective to achieve sustainable development (UNFCCC 2015; UN General Assembly 2015). For example, increased levels of warming may narrow the choices and options for sustainable development. However, it is important to remember that the Paris Agreement is not static; it is designed to enhance the national efforts of countries over time, which means that current commitments only represent the basis of climate change ambitions. To this end, the largest reduction in GHG emissions is scheduled to happen by 2030 and 2050, and the agreement should provide the tools and innovative approaches to make it happen (NRDC 2021). Furthermore, as reported by the IPCC Working Group II (WGII) contribution to the Sixth Assessment Report (AR6) (IPCC 2022), recent studies assessing the links between development and climate risk shows that actions taken to achieve the goals of the Paris Agreement could undermine progress toward some of the SDGs. Effective sustainable development pathways in this regard are also those that consider the impact of any mitigation and adaptation measures on marginalised and vulnerable people (Hickel 2017). Although considerations of social difference and access to justice might be included in some of those measures, the assumption that economic growth increases opportunities for all, and distributes the newly created financial resources equally, might not be correct, coupled with climate change impacts affecting the most vulnerable sectors of society more disproportionately (Diffenbaugh and Burke 2019) *(medium confidence).*

Achieving the SDGs and consolidating the shift to sustainable development pathways is still possible by the deadline of 2030 if a more ambitious climate policy, international climate finance, gradual redistribution of carbon pricing dividends, technological progress, less resource-intensive

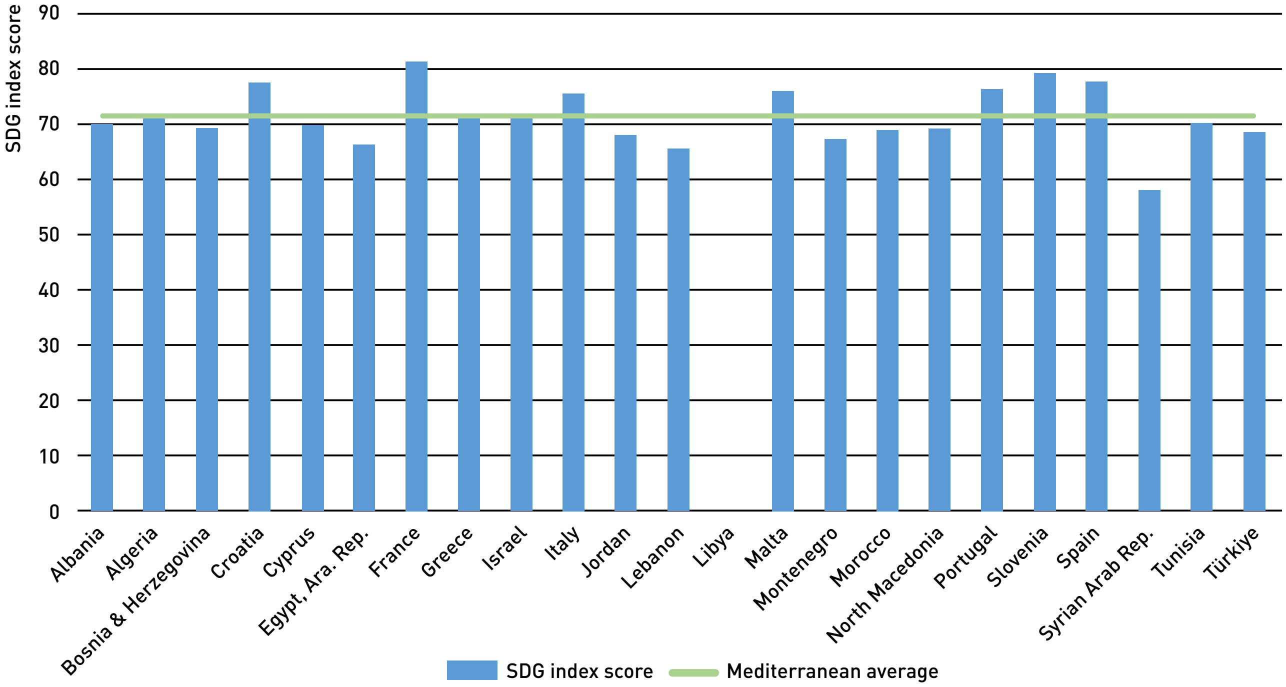


Figure 5.1 | Mediterranean SDG index score. The SDG Index tracks country performance on the 17 SDGs as agreed by the international community in 2015. All 17 goals are weighted equally in the Index. The score signifies a country's position between the worst (0) and the best or target (100) outcomes. The Mediterranean region has an average index score of 71.6 (green bar), hypothetically corresponding to the 49th position of the world rank. Source: Sachs et al. (2019b).

lifestyles, and improved access to modern energy are undertaken in the short-term (2021–2040), as also shown by *Figure 5.1* (Soergel et al. 2021) *(low confidence).*

In 2019, the Sustainable Development Solutions Network published a report which focused on the performance of 23 Mediterranean countries with regards to the SDGs. The report states that the average SDG index for the region reached 71.6 which corresponds to the 49th position in the world rank, and therefore, almost 72% away from the best possible outcomes across the 17 SDGs. The countries registering the most progress with most SDGs are NMCs. Good progress was also made by most Mediterranean countries in the provision of basic services and infrastructure, particularly under SDG 1 (no poverty), SDG 3 (good health and well-being), SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy) and partially in SDG 8 (decent work and economic growth). However, the report points out that even the countries topping the list are far from achieving the highest score of 100 (Sachs et al. 2019b).

5.3.1.1 Pathways for sustainable energy and climate mitigation

Mediterranean countries have a very different mix of energy sources; while most countries are net energy importers others are net energy exporters. These differences complicate envisioning a common pathway for sustainable energy and climate mitigation in the Mediterranean, and even planning observations that can be applied to the region as a whole *(medium confidence).* It is undeniable that the Mediterranean region would benefit from sustainable energy and climate mitigation pathways, since energy and climate issues are at the forefront in the Mediterranean region. Fostering a sustainable and future-proof socio-economic development model based on sustainable low carbon energy and climate mitigation pathways is also an essential component of regional stability (Antonelli et al. 2021) *(medium confidence).*

The EU Green Deal has been framed as a broad political vision that summarises the EU's energy, climate, economic and geopolitical goals of achieving climate neutrality by 2050, supporting measures to reduce the carbon footprint of hydrocarbon production and energy efficiency (EC Secretariat-General 2019). Hydrogen can be a key enabler of Mediterranean decarbonisation intentions, as there is unprecedented momentum for capital-intensive hydrogen projects, including across the Mediterranean *(low confidence).* Accordingly, when promoting green energy and climate mitigation pathways in the region, preference will likely go to low-carbon projects that will in fact contribute to reducing global warming and achieving socio-economic goals in the region, compared to other solutions. They also appear to be future-proof, consistent with net zero targets by mid-century (Antonelli et al. 2021) *(medium confidence).*

All Mediterranean governments must implement clear action plans to close the electricity access gap, backed by determined leadership, increased investments and targeted policies and regulations. Multi-stakeholder partnerships and scaling up to support investments in clean energy across all sectors of the industries introducing the transition to clean energy is essential for reaching the net zero goal by 2050 (Sachs et al. 2019b).

SEMCs have natural resources that provide opportunities for low-carbon energy production. However, the share of renewable energies in total energy consumption remains low because of widespread fossil fuel subsidies, regulatory restrictions, and limited electrical connectivity *(high confidence).* Clean energy still accounts for a relatively small share of North-South trade. In this context, SEMCs may use green and blue hydrogen as crucial elements of their decarbonisation strategy, such as the initiatives of countries like Egypt, Morocco, and Tunisia, which have recently signed bilateral agreements with Germany for green hydrogen projects *(Figure 5.2)* (Moreno-Dodson et al. 2021).

5.3.1.2 Pathways for sustainable coastal tourism

The Mediterranean attracts about one third of global tourism and it was the main tourist destination in 2019 (Plan Bleu 2022b). Coastal tourism worldwide is likely to reach 26% of the total ocean industry added-value in 2030, becoming the largest blue economy sector (OECD 2016) *(high confidence).* At the same time, this type

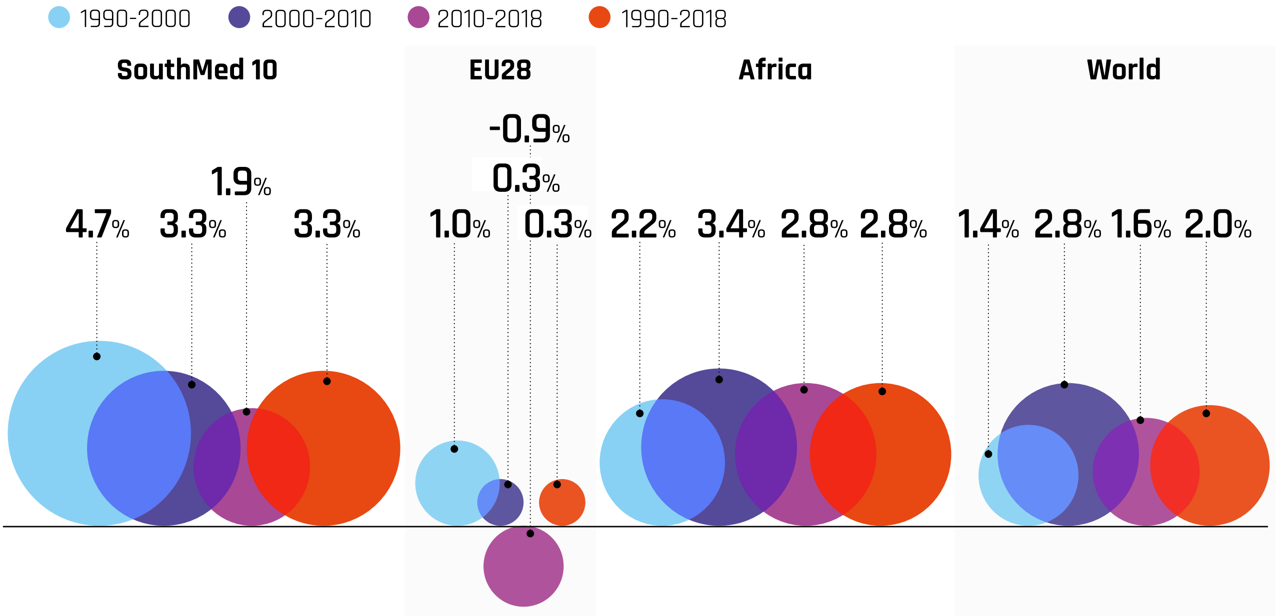


Figure 5.2 | Primary Energy Consumption, annual average growth rates, southern/eastern Mediterranean and other regions. Source: Moreno-Dodson et al. (2021).

of tourism is among the sectors most impacted by climate change, especially in the Mediterranean Basin (Bocci et al. 2018; Tonazzini et al. 2019). Climate change has a significant impact on coastal ecosystems, as it modifies both weather conditions and hydrodynamic processes (e.g. sea level rise, water scarcity, coastal erosion, increase in storm surges, increase in frequency and height of tides). Major climate change impacts affecting Mediterranean tourism destinations include water scarcity, warmer summers, climate instability, marine and coastal biodiversity loss, and increases in disease outbreaks (Simpson et al. 2008; Magnan et al. 2013; MedECC 2020b). These impacts, although not yet perceived as relevant, are going to worsen in the medium- and long-term future (Bocci et al. 2018) *(medium confidence).*

Climate and weather, as well as safety, are important factors in tourists' decision-making and influence the successful operation of tourism businesses (Gómez Martín 2005; Becken 2010), destination choices and therefore, tourist flows. Islands are particularly vulnerable to the above-mentioned risks because of their strong dependency on the ecosystem services provided directly (e.g. fish and seafood) and indirectly (coastal and maritime tourism) by the sea, together with natural resources and space constraints (Tonazzini et al. 2019). For instance, Mediterranean top tourism destinations such as Malta, Corsica, Balearic Islands, Sicily and Sardinia have been experiencing population congestion and over development in recent decades (Manera et al. 2016; M. Briguglio and Moncada 2020) *(high confidence).*

While NMCs are a rather mature tourism destination, some SEMCs have only recently experienced a significant growth in coastal tourism (e.g. Egypt, Türkiye). One of the consequences of this is that most of the pressures associated with this economic sector tend to be stationary in the NMCs, whereas there are likely to increase in the coming years in SEMCs (Randone et al. 2017; Tonazzini et al. 2019). In addition, some Mediterranean countries (Egypt, Israel, Jordan, Lebanon, and Palestine) are *likely* to be most impacted by climate change in the medium (2030) and long term (2050) (Bocci et al. 2018) *(medium confidence).*

Since Mediterranean coastal tourism causes environmental and social impacts which negatively affect its own existence with a loop effect (Randone et al. 2017; Drius et al. 2019), there is an urgent need to reduce such impacts in the region in order to comply with the SDGs of the 2030 Agenda for Sustainable Development and the Mediterranean Strategy for Sustainable Development 2016–

2025 (MSSD 2016–2025)[81], specifically addressing measures that reduce the impacts of tourism on climate change *(high confidence).* The SDGs explicitly related to coastal tourism are SDG 8 (sustainable economic growth), SDG 12 (sustainable consumption and production) and SDG 14 (ocean and coastal areas conservation) *(medium confidence).*

While there is not yet a definitive consensus on whether with warmer temperature the overall number of tourists will increase (Katircioglu et al. 2019) or decrease (Torres et al. 2021), it is evident that national and regional authorities must implement policies to adapt, for instance, to the *likely* increase in energy and water demand, in addition to actively promoting sustainable practices and actions to reduce energy and water consumption. Increasing attention has been focused on how climate change might impact tourist destinations (Wall and Badke 1994) and how they might adapt to minimise risks and maximise opportunities (Becken and Hay 2007a). These challenges could be addressed by providing credible, comprehensible, diverse, and replicable alternative tourism models (Randone et al. 2017) *(high confidence).* One example in this sense is ecotourism, a sustainable alternative to traditional tourism practices in coastal and maritime areas, which promotes local communities and the conservation of natural resources. This type of tourism is increasing in popularity even in the conventional tourism market (chain hotels, large resorts, premium cruise ships) (Tonazzini et al. 2019). Sustainable tourism models are also encouraged by various international organisations (e.g. UfM) and programmes (e.g. Interreg MED Community 'Sustainable tourism' financed by the EU)[82] Very recently, the Glasgow declaration for climate action in tourism has been receiving attention from public and private organisations who commit to implement a series of actions to cut tourism emissions (One Planet Sustainable Tourism Programme 2021) *(medium confidence).*

An additional pathway to coastal tourism sustainability could be a set of policy tools that national and local governments can use to facilitate sustainable tourism. These range from green taxes, directed to penalise practices that are harmful to the environment, to sustainable tourism indicators and eco-labelling tourism schemes (Randone et al. 2017) *(high confidence).* Many Mediterranean countries have developed their own Integrated Coastal Zone Management (ICZM) — a multidisciplinary and iterative process to promote sustainable management of coastal zones. Morocco, for instance, has put in place a series of measures to tackle coastal erosion, which have implications on tourism-related infrastructure, such as reducing the removal of beach sand and riverbed aggregates to be used as building materials; restricting the urbanisation of the coasts; introducing beach monitoring programmes, protection and regeneration of some of the remaining dunes; and strengthening of watershed erosion protection through replanning of dams (Bocci et al. 2018) *(high confidence).*

5.3.1.3 Pathways for sustainable small-scale fisheries

Small-scale fisheries contribute significantly to the livelihoods and food security of coastal populations along the Mediterranean Sea *(high confidence).* Their contribution is crucially important to the more vulnerable populations, particularly in rural coastal communities. Small-scale fisheries represent over 84% of the total fishing fleet, employ nearly 62% of the total workforce on board fishing vessels, account for 29% of total revenue from marine capture fisheries, and claim 15% of the total catch (FAO 2020). Revenue is distributed disproportionately between small-scale fisheries and industrial fisheries, with significant variation across countries. The contribution of small-scale fisheries to total fishery employment ranges between 70 and 80% in Türkiye, Tunisia, Croatia, France, Slovenia, Lebanon, Greece, and between 25 and 35% in Algeria, Egypt, and Spain (FAO 2020).

Over 80% of the fish stock in the Mediterranean is threatened by overfishing, sometimes at rates six times higher than the maximum sustainable yields practice *(high confidence)*, a practice that is

---

[81] https://www.unep.org/unepmap/what-we-do/mediterranean-strategy-sustainable-development-mssd

[82] https://sustainable-tourism.interreg-euro-med.eu

bound to reflect negatively on small-scale fishers. The pathway to sustainable small-scale fisheries would require the meaningful participation of small-scale fishers in the co-management of the sector to minimise the long-term impacts on the fish population and the livelihood of fishing communities. Specific actions to limit overfishing would include promoting best practices to maximise the value of the catch by directing fishing activities towards the catch of selective, high-value products and supporting fishers by creating vertically-integrated distribution channels (Randone et al. 2017). Income diversification, through the creation of alternative job opportunities, would also contribute to the well-being of fishing communities. The Regional Plan of Action for Small-Scale Fisheries in the Mediterranean and the Black Sea (RPOA-SSF) recommends strengthening value chains, improving market access for small-scale fisheries products and increasing the profitability of the sector.[83]

5.3.2 Scenarios and pathways to achieve the Sustainable Development Goals (SDGs)

Sustainable development pathways are part of different scenario frameworks developed by the research community to describe major social, economic, and environmental developments including those achieved through climate change adaptation and mitigation measures. There are multiple possible pathways by which the Mediterranean region can pursue sustainable and climate-resilient development. There is robust evidence that current development pathways are leading away from sustainable development (IPCC 2022) *(high confidence)*. On the other hand, pursuing sustainable development goals and climate resilience increases their effectiveness.

5.3.2.1 Best practices and successful case studies in Mediterranean coastal areas

The case of cruising: pathways to sustainability?

Worldwide, the ocean cruise industry is one of the most dynamic segments of the tourism sector, with 31.7 million passengers in 2023 — surpassing pre-pandemic 2019 levels by 7%. The industry is expected to continue this upward trend, with passenger volume projected to exceed 2019 levels by more than 12% by the end of 2026 (CLIA 2022b, 2023a). It is a highly impacting sector in terms of CO_2 emissions, from ship building to ship dismantling, as well as polluting harbours and their inhabitants (Lloret et al. 2022) *(high confidence)*. The actual cruise shipbuilding process

---

[83] https://openknowledge.fao.org/handle/20.500.14283/cb7838en

takes two to three years and should follow a technical measure for reducing CO_2 emissions, the Energy Efficiency Design Index, whose requirements are tightened every five years (Tonazzini et al. 2019). When finally dismantled, the disposable vessels comprise a vast range of hazardous substances such as PCB, asbestos, and waste oil products (Tonazzini et al. 2019) *(high confidence).* Cruise ships in operation are the most carbon intensive means of transportation: according to Howitt et al. (2010), a voyage ranges from 250 to 2200 g of CO_2 per passenger per kilometre. Cruise ships operate on fuels rich in carbon and sulphur and their engines are kept running close to city centres. In the Mediterranean Basin, cruise ship traffic is second only to the Caribbean, and it has been producing increasing air pollution in ports over recent years, with three top cruise terminals, in terms of emissions: Barcelona, Palma de Mallorca (Spain) and Venice (Italy) (Karanasiou 2021) *(high confidence).* The case of Venice has been largely studied, showing how cruise tourism is a complex issue in relation to sustainability, as many actors involved in the market identify benefits and costs (also in terms of environmental impacts) of the cruise industry in different ways (Asero and Skonieczny 2018). This considered, a long-term management strategy involving international agencies, cruise line operators and host communities seems to be a reasonable pathway towards sustainability. There is no international coordination of the cruise industry at the regional level, which leaves the Mediterranean area open to exploitation (Asero and Skonieczny 2018) *(medium confidence).* A remarkable step for the reduction of the environmental impacts caused by the cruise industry has been the approval of the designation of the Mediterranean Sea as an Emission Control Area (ECA) for sulphur oxides (SO_x) and particulate matter (IMO 2022).[84] This measure will be effective on 1 May 2025 and should lead to a 79% reduction in sulphur oxide emissions and a 24% reduction in fine particles (Plan Bleu 2022a) *(medium confidence).*

An increasing number of cruise companies voluntarily report on their environmental impact. However, those reports are often 'self-assessments' and can therefore be too focused on 'soft' indicators, not always including full carbon footprint, quality of employment or human rights enforcement (MacNeill and Wozniak 2018) *(medium confidence).*

A concrete measure to reduce CO_2 emissions and air pollution is the electrification of ports, called Short-Side Electricity (SSE), also known as cold-ironing, which allows cruise ship operators to turn off the ship engines while in port (Stolz et al. 2021) *(high confidence).* Winkel et al. (2016) found that SSE offers the potential to reduce CO_2 emissions by over 800,000 tons in Europe alone. This technology is currently available in few berths worldwide (64 in Europe; 9 in Asia), whereas only 25 cruise vessels are equipped with the necessary technology for shore power connection. The main disadvantages of SSE are the relevant initial investments, and the lack of know-how needed to let cruise lines and ports cooperate. In addition, the electricity provided should originate from renewable resources. SSE does not only address climate action (SDG 13), but encompasses nine SDGs: SDG 3 (good health and well-being), SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), SDG 11 (sustainable cities and communities), SDG 13 (climate action), SDG 14 (life below water), and SDG 15 (life on land) (Stolz et al. 2021) *(high confidence).*

Cruise ship tourism is gaining in popularity with movements within the Mediterranean tripling in the last decade with 13,194 cruise ship calls in 2015 (MedCruise 2017) *(high confidence).* This increase in cruise ship tourism, while increasing the financial performance of cruise and port operators, might also carry negative effects on unique Mediterranean ecosystems and on the social fabric of some of the visited communities, due to changes in traditional value systems and

---

[84] At their 22nd meeting, the Contracting Parties to the Barcelona Convention adopted Decision IG.25/14 agreeing to submit a joint and coordinated proposal to designate the Mediterranean Sea, as a whole, as an Emission Control Area for Sulphur Oxides (Med SOX ECA) under Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL). The proposal was submitted to the International Maritime Organization's Marine Environment Protection Committee (MEPC) for consideration at its 78th session, held from 6 to 10 June 2022. At that session, the MEPC approved the designation of the Med SOX ECA. See also: https://www.rempec.org/en/news-media/rempec-news/mediterranean-sea-emission-control-area-for-sulphur-oxides-and-particulate-matter-med-sox-eca-approved-by-the-imo2019s-marine-environment-protection-committee

lifestyles at destinations, including gentrification (Jones et al. 2016; Mejjad et al. 2022). The average dimension of a modern cruise ship is 200 m long, 26 m beam, and a passenger capacity of 3220 people. This marks a shift from the early 2000s, when there were very few ships carrying more than 2000 people (Pallis 2015). In fact, these ships can well be compared to 'floating cities' resulting in the generation of large waste volumes which includes sewage, wastewater from bathrooms, hazardous waste, solid waste, oils, etc. (Tonazzini et al. 2019). Waste reception facilities are therefore a necessity in ports with containers being the basic storage method offered for most waste except cooking oil. According to Pallis et al. (2017), who analysed 52 cruise ports in the Mediterranean Sea, waste segregation is limited due to the fact that the majority of ports of call assign this job to an external contractor with most waste ending in landfill, followed only marginally by recycling. The latter relates to plastic waste, whereby 80% of Mediterranean cruise ports recycle plastic waste (Pallis et al. 2017) *(high confidence).* Measures to address water pollution and waste segregation and disposal may include technological applications for on-board water treatment, the use of eco-friendly cleaning and anti-fouling products, and fiscal measures to incentivise reduced waste production both for ships and for ports and marinas (Plan Bleu 2022a) *(high confidence).*

5.3.2.2 Transformative pathway for sustainable development

5.3.2.2.1 Transformation pathways for climate resilience

Transformative actions are increasingly urgent across all sectors, systems, and scales to avoid exacerbating the risks of climate change, and to meet SDG targets. In the context of climate resilient pathways, transformative actions concern leveraging change in the five pillars of development that drive societal choices and climate actions, toward sustainability such as, social cohesion and equity, individual and agency, and knowledge developments, which have been identified as steps to transform practices and governance systems for increased resilience. However, in some cases, transformative actions face resistance from the political, social, and/or technical systems and structures they are attempting to transform. There is mounting evidence that many adaptation efforts have failed to be transformative, but instead have increased inequality and imbalance, especially when following free market measures too strictly. Marginalised and vulnerable groups would therefore need to be placed at the centre of adaptation planning (Veland et al. 2013; Atteridge and Remling 2018; Reckien et al. 2023a, Reckien et al 2023b).

5.3.2.2.2 Transformation pathways to achieve the SDGs and challenges

The need for coordinated transformational action schemes is a pressing concern. Achieving the 17 SDGs and the goals included in the 2015 Paris Agreement is challenging and complex. However, prioritising the following six major societal transformations can foster the achievement of those goals: quality education (SDG 4); access to good quality and affordable health care (SDG 3); renewable energy, and a circular economy (SDGs 7, 12, and 13); sustainable land and marine management (SDGs 2, 14, and 15); sustainable urban infrastructure (SDGs 6, 9, and 11); and universal access to digital services (SDG 9). In this context, cooperation among actors and partnerships to achieve all goals (SDG 17) acquires an even more important role. Each transformation contributes to several SDGs and describes a significant change in the social, economic, political, and technological framework to achieve sustainable development over the long term. Dropping any of them will make achieving the SDGs even more challenging. The six transformations can be implemented in every country to help address trade-offs and synergies across the SDGs (Sachs et al. 2019a).

The six societal transformations operate at the global, regional, and national levels. They must be adapted to country contexts, such as levels of development, natural resource base, and ecosystem governance challenges and structures. Each of the six transformations requires a significant scaling-up of public investments, and coordination among public and private authorities and civil society. However, the financing needs for SDG investments are far greater than the fiscal space available to governments of low-income developing countries (Sachs et al. 2021).

5.4 Social equity and climate justice

5.4.1 The links between social inequalities and sustainable pathways in coastal communities

The social and economic characteristics of coastal communities differ greatly across the Mediterranean Basin. These are informed by a clear difference in the levels of human development, as captured by the Human Development Index (HDI), ranging from a ranking of 150th (over 189 countries) for The Syrian Arab Republic, and 123rd for Morocco, to the very high development of Israel (22nd) and Malta (23rd), or in the levels of per-capita wealth, ranging from the 4192 USD Gross National Income (GNI) of Syria to the 42,840 USD of Italy (UNDP 2022). Historical events, including colonisation and conflicts, have also played a major role in shaping the current levels of well-being, governance, and social status of many citizens across the Mediterranean (Gürlük 2009). Furthermore, economic policies that prioritised strict macroeconomic balancing measures and short-term gains for a selected number of stakeholders, at the expense of long-term sustainable development for a larger part of society, are also responsible for growing social inequalities in the Mediterranean region (Lehndorff 2012). Examples in this area can be found in the excessive privatisation of health and education services, which, when faced with a crisis like the COVID-19 pandemic, brought many countries (Assa and Calderon 2020) to the realisation that the original gains obtained from the budget cuts were overwhelmingly outweighed by the costs incurred to deal with such an emergency, compounded by the lack of preparedness often linked to reduction in budgets for these crucial sectors (Williams 2020) *(medium confidence).*

Climate change is adding a further layer of constraints to existing social inequalities, especially on women, the elderly and children (Ali et al. 2022). Young people, who are the fastest growing population in the eastern and southern Mediterranean region, are potentially the most affected by climate change. Infants and children are less able to survive extreme weather events and diseases, particularly those living in poverty and experiencing displacement (Al-Jawaldeh et al. 2022). In recent years, coastal communities have experienced an increasingly higher level of social inequalities, which, besides cyclical socio-economic drivers, tend to be more pronounced due to the specific pressure that climate change extremes exert on coastal areas (Lionello et al. 2021). The capacity to respond to climate extremes, and more general disasters, is often linked to development levels, with the assumption that the higher the wealth and the lower the social inequalities, the better the capacity to cope in the short term and adapt in the long run (L. P. Briguglio 2016). Therefore, existing social inequalities can act as a further barrier to climate change adaptation, and more generally to sustainable development pathways. Addressing social inequalities among coastal communities can therefore be an important tool to promote better adaptation and ensure sustainable development pathways (Cinner et al. 2018) *(high confidence).*

To this end, it is crucial to identify a number of best practices in Mediterranean countries that while reducing social inequalities, can support post-pandemic climate resilient socio-economic systems. Among these, the use of economic instruments, such as taxation and subsidies, play a central role in supporting the most vulnerable categories (Panayotou and UNEP Environment and Economics Unit 1994; Bräuninger et al. 2011). The successful practices have the potential to also be scaled-up to other countries in the Mediterranean Basin. However, for this to happen, besides forward-looking policymaking, there must be an opportunity to improve existing gaps in data collection within and among countries in the Mediterranean Basin, thus providing policy with data that can drive policy models potentially in many settings *(medium confidence).*

5.4.2 Access to social infrastructure

Social infrastructure includes health, educational, cultural and environmental factors that enhance social comfort (Torrisi 2009). Availability of, and access to social infrastructure such as schools, hospitals, green areas, and cultural spaces are among the standard indicators of the quality of life of a country. Poor healthcare, cultural services and education affect the poor ranking of Mediterranean cities, such as Algiers, Damascus and Tripoli in the Global Liveability Index (EIU 2022).

The COVID-19 pandemic also drove a move down in the ranking of some European Mediterranean cities such as Barcelona, which, in 2022 alone, fell 19 places. Social infrastructure also has positive impacts on social cohesion, by ensuring equal access to basic services (such as healthcare and education) across cities and regions (OECD 2021) *(high confidence).* On the other hand, existing disparities in access to social infrastructure can exacerbate pre-existing inequality within and among countries and undermine social cohesion. In the EU, the importance of bridging critical social infrastructure gaps to ensure sustainable and climate resilient development has been emphasised in the aftermath of the COVID-19 pandemic, when in several countries, including European Mediterranean countries such as Greece and Slovenia, over 50% of households were at risk of descending into poverty (CEB 2020). Here, investments in social infrastructure such as schools, health and social care services can help to advance several SDGs, including SDG 3 (health), SDG 4 (education) and SDG 5 (gender equality). According to a recent OECD study (OECD 2020), only a few regions in the OECD area have achieved the outcomes suggested for SDG 3 and SDG 4, with significant inequalities existing within countries, including Mediterranean countries, such as France and Spain. For SDG 4, for example, while the Basque country has achieved the end value for the used indicators (i.e. bring school dropout rates to 8% or lower and tertiary education to at least 46% of the adult population), the Balearic Islands are halfway to meeting it *(medium confidence).*

In terms of gender equality, where the indicators used for SDG 5 are the same employment rate and part-time employment for both women and men, the Mediterranean countries with the most significant regional disparities are Türkiye and Israel (OECD 2020). Here, eastern Anatolia and the North of Israel are the two farthest regions that perform the lowest to the end values in the respective country, while the capital regions (eastern Black Sea and Tel Aviv) are the best performing regions. However, the country that displays the greatest disparities in employment for women and men across its cities is Italy, with the coastal city of Venice facing one of the largest possible distances to the end value for SDG 5 *(medium confidence).*

5.4.3 Inclusion

Social inclusion is a context-dependent concept (Silver 2015) which depends on several factors including availability of resources, mechanisms and processes that enhance people's capabilities and opportunities to participate in economic, social, cultural and political arenas. Being multidimensional and dynamic, social inclusion can be hardly measured, especially when standard data sources across countries are lacking (UN DESA 2016). With respect to the Mediterranean, available literature (e.g. ILO 2016; UN DESA 2016; Capasso et al. 2018) shows that lack of social protection, informal and insecure employment and high numbers of young people not completing secondary education affect the SEMCs in particular (Egypt, Lebanon, Morocco, Palestine, Tunisia, Türkiye), and especially young women (Murphy 2018) *(high confidence).* In these countries, and mainly in Egypt, relatively higher income inequality has also been observed (Alvaredo et al. 2014, Alvaredo et al. 2019). Also, NMCs, which are generally more inclusive than the SEMCs, if compared with northern European countries show limited welfare protection and greater socioeconomic inequalities (Conde-Sala et al. 2017) *(medium confidence).*

In both northern and southern Mediterranean countries, segregation and disempowerment of migrants, due to informal work arrangements and little or no union activity, limit social inclusion, especially of some groups, such as agricultural workers. This notwithstanding, and although youth unemployment is higher in many southern European cities than in some SEMCs (e.g. in Moroccan cities; Surian and Sciandra 2019), the share of young people (15 to 34-year-olds) migrating or willing to migrate from SEMCs to EU countries increased over the past decades, and particularly in the aftermath of the Arab uprisings (De Bel-Air 2016). In 2020, Moroccans were the largest group among new EU citizens (EMN 2021)[85]

---

[85] See also EUROSTAT online database, https://ec.europa.eu/eurostat/statistics-explained/index.php

and the largest number of migrants from Africa living abroad, after Egyptians (McAuliffe and Triandafyllidou 2021). Yet, despite being relatively better integrated in their destination countries than other foreign immigrant communities, their cultural integration remains low (e.g. in Italy: Di Bartolomeo et al. 2015) *(high confidence).*

Climate change can also be a driver of social inclusion as it pushes cities and communities to interconnect and address the common challenges of climate change together, for example by promoting common cultural heritages, including the Mediterranean diet (Tarsitano et al. 2019) *(low confidence).*

However, climate change impacts can also be a limit to social inclusion. The main economic sectors in the Mediterranean region, including fisheries and agriculture, are highly vulnerable to climate-related risks (such as flooding, storms, heatwaves, and sea level rise) and coastal communities and ecosystems are among the most negatively affected by these impacts. Projected increases in climate hazards in the Mediterranean region can put at risk marine species and coastal systems with limited adaptation options, especially in SEMCs (Linares et al. 2020), where capacity to adapt is minor and decreases in food production on land and from the sea can affect income, livelihoods and food security, and further erodes people's economic and social rights *(medium confidence).*

Yet, as discussed by the WG2 contribution to AR6 (IPCC 2022b), social processes can promote transformative adaptation, including in the Mediterranean Basin, where the implementation of institutional frameworks can enhance human rights protection and reduce risks of conflict, displacement and human insecurity (MedECC 2020a) *(high confidence).* Inclusive and participatory approaches exist in Mediterranean countries, as documented for example in the water sector by Iglesias and Garrote (2015), and can be used to promote climate resilient sustainable development pathways in the region. In coastal communities, adaptation responses to climate change include structural defence, ecosystem protection and restoration, and livelihood diversifications. However, these often come with negative gender outcomes that lead to the exacerbation of inequalities (Prakash et al. 2022) and negatively impact the attainment of SDG 5 for gender equality *(medium confidence).*

As highlighted in the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) of the IPCC (2019), densely populated coastal zones are places at risk, particularly for women and girls, since they have less access than men and boys to information and training on disaster preparedness and response *(high confidence).* However, there is a lack of studies focused on gender in the context of coastal hazards in the Mediterranean region, which generates a gap of knowledge in this respect.

5.4.4 Gender, climate justice, and transformative pathways

The achievement of sustainable development commitments, such as the SDGs, requires transformative changes in social and ecological systems. These transformations are associated with questions such as gender equality, equity, poverty reduction and justice, which are at the core of climate-resilient development. The main sustainable development pillars in Mediterranean countries vary in terms of exposure to key risks, as shown in *Table 5.4*.

Climate change impacts exacerbate social inequalities (IPCC 2022b; UNDP 2022) and its consequences are felt disproportionately by the most vulnerable sectors of the population, including children, young people, migrants, and women (IPCC 2022b). Transformative pathways toward climate-resilient development can be more effective if they reduce inequalities and promote gender equality, prioritising equity and justice in adaptation planning and implementation *(high confidence).*

Achieving climate-resilient development in coastal zones requires synergies between SDG 13 (Climate Action) and SDG 14 (Life Below Water), and the adoption of adaptation measures that, while helping coastal communities to face the risks associated with climate change (e.g. ocean warming and acidification), contribute to the achievement of other SDGs (SDG 1 – Poverty, SDG 2 – Hunger, SDG 3 – Good Health and Well-Being) (IPCC 2022b; Schipper et al. 2022). An example is coastal-focused adaptation measures that bring technological and infrastructural improvements to fisheries and aquaculture, which are crucial sectors for food security and the economy of the Mediterranean (Cramer et al. 2018).

Developing transformative coastal adaptation pathways across the Mediterranean can also contribute to the achievement of SDG 5 (gender equality) *(high confidence)* by empowering women's participation in decision-making and support programmes, for example, in the fishery sector, where women are actively involved, but paid less than men and largely absent from top management positions (FAO 2023). This is particularly true for the Mediterranean countries where gender-based inequality is higher — for example, Algeria, Syria, Egypt, Lebanon, and Morocco, which ranked between the 104th and the 126th position (out of 191) in the global ranking of the Gender Inequality Index (GII) (UNDP 2022).

5.4.5 Diversity

Diversity in natural and human systems is an inescapable fact that depends on the existence of variety and variability among living organisms and societies. When it comes to social equity and climate justice, the concept of diversity is preferable to uniformity, since climate change impacts are not felt evenly across populations, and the ability to adapt varies across different countries and sectors of society. Therefore, response capacity to climate change impacts must be increased, and resources concentrated, where vulnerability to climate change is higher.

In the Mediterranean region, there are differences that stem from biological diversity and socio-cultural richness, but also from history, and diverse socio-economic and human development conditions (with some countries, such as Israel and the EU Mediterranean countries in the highest human development category and others, such as Syria, in the lowest) (dos Santos et al. 2020; UNDP 2022).

These differences are not necessarily taken into account by existing assessment models, including those developed to describe climate change impacts on Mediterranean marine and coastal ecosystems, where climate change, in combination with other global change drivers, such as urbanisation, rural exodus, population growth and tourism (Senouci and Taibi 2019; Petrișor et al. 2020) exacerbate existing environmental problems (Cramer et al. 2018). On the other hand, regionalised Shared Socioeconomic Pathways (SSP), which account for differences between countries in the Mediterranean region, can be used to better assess future exposure, vulnerability and impacts of climate change in different coastal zones (Reimann et al. 2018) *(medium confidence).*

5.4.6 Access to climate finance funds

There are different challenges linked to obtaining access to climate finance, especially when zooming in on specific parts of a country, such as coastal areas. For instance, large-scale infrastructure projects, mainly for mitigation purposes, are more successful in attracting funding than small-scale adaptation projects at local levels (Costa et al. 2022) *(medium confidence).* The main challenge for the Mediterranean region, especially the SEMCs, is upscaling the level of funds available to meet urgent financing needs to support sustainable pathways toward a climate transition. Most of the funds are driven by public sector initiatives with minimal, or little effort by the private sector, with only Egypt issuing green bonds to date (Costa et al. 2022). This limits the mobilisation of private funds that can support the need to achieve an effective transformative and sustainable change. The UNFCCC defines climate finance as 'local, national, or transnational financing — drawn from public, private, and alternative sources of financing — that seeks to support mitigation and adaptation actions that will address climate change'.[86] Climate finance refers to the investments necessary to transition the world's economy to a low-carbon path, to reduce greenhouse gas concentrations levels, and to build resilience of countries to climate change (Hong et al. 2020). The NMCs are viewed as leaders and pioneers of green finance, with an important developing market whereas the SEMCs

---

[86] https://unfccc.int/topics/introduction-to-climate-finance

Table 5.4 | Environment, Social, and Governance (ESG) Risk Ratings in the Mediterranean. Source: Economic Intelligence Unit (EIU), https://www.eiu.com/n/solutions/esg-rating-service/, accessed on September 20, 2023.

EIU's Environment, Social, and Governance (ESG) Risk Ratings				
Country	**Overall Assessment**	**Environment**	**Social**	**Governance**
Albania	No Data	No Data	No Data	No Data
Algeria	High	High	High	High
Bosnia & Herzegovina	No Data	No Data	No Data	No Data
Croatia	Low	Low	Low	Low
Cyprus	Low	Low	Low	Low
Egypt	High	Moderate	Very High	High
France	Very Low	Very Low	Low	Very Low
Greece	Low	Very Low	Low	Low
Israel	Low	Moderate	Low	Low
Italy	Low	Low	Low	Low
Lebanon	High	High	Moderate	High
Libya	No Data	No Data	No Data	No Data
Malta	No Data	No Data	No Data	No Data
Monaco	No Data	No Data	No Data	No Data
Montenegro	Moderate	High	Low	Moderate
Morocco	Moderate	Moderate	Moderate	Moderate
Palestine	No Data	No Data	No Data	No Data
Slovenia	Very Low	Very Low	Very Low	Low
Spain	Very Low	Low	Very low	Very low
Syria	No Data	No Data	No Data	No Data
Tunisia	Moderate	Moderate	Moderate	Moderate
Türkiye	High	Moderate	High	Moderate

are struggling with inadequate flows of funds to make a transition towards a green economy to fulfil the objectives of the Paris Agreement (Costa et al. 2022) *(medium confidence).*

In accordance with the principle of 'common but differentiated responsibility and respective capabilities' (CBDR-RC), industrialised countries are to provide financial resources to assist the less developed and developing countries in implementing the objectives of the UNFCCC (UNFCCC 2015). International climate finance commitments to the SEMCs accounted for 11% of total global financial flow in 2019, amounting to USD 9.12 billion, with bilateral donations comprising around 37% of the overall amount (Costa et al. 2022). Major bilateral donors include EU institutions (excluding the European Investment Bank, France, and Germany). Multilateral climate funds provided the smallest share of overall climate finance to the SEMCs with only 2%. SEMCs differ in their abilities to access climate funding, with Türkiye, Egypt, and Morocco being most successful, while other countries such as Jordan, Syria, Libya, Algeria, and Montenegro have experienced difficulties (Midgley et al. 2018) *(medium confidence)* .

Alternative scenarios, ranging from all green, shades of green, brown (finance as usual), and crisis and conflicts, for the future of green and climate finance will likely produce dramatically different outcomes depending on political, regulatory and market factors (Costa et al. 2022). The all-green scenario entails NMCs stepping up their financial commitments and delivering beyond their pledges to provide sustainable finance to SEMCs in addition to fostering Euro-Mediterranean cooperation to develop a common strategy and knowledge sharing, and establish common standards and reporting measures. The SEMCs, in turn, need to institute reforms to improve the business environment and allow the use of innovative instruments such as green bonds, guarantees and public-equity co-investments, etc., to ensure the flexibility and attractiveness of green and climate finance. The all-green scenario will produce large, bankable and transformative projects in the energy, building and transport sectors across the Mediterranean. In parallel, green finance reaches small projects benefiting local communities and creating decent and sustainable jobs, contributing to a fair and just transition (Costa et al. 2022) *(medium confidence).* According to Climate Policy Initiative (2021), global climate finance flows reached USD 632 billion in 2019/2020 recording a timid 10% increase relative to the average increase of 24% in previous periods. However, to meet climate objectives by 2030, annual climate finance must increase by at least 59% to USD 4.35 trillion in order to maintain a 1.5-degree trajectory *(high confidence).*

5.5 Final remarks and knowledge gaps

Further research is needed in the area of sustainable energy transition, where gaps exist to identify current energy needs, also in the light of the increasing electrification of transportation fleets, and the socioeconomic categories most at risk when measures are implemented to achieve such a transition.

To support a faster and equitable transition to sustainable development pathways, this is essential to increase investments in research and development to identify the right mix in the use of:

- command and control (laws, regulations, etc.);
- economic instruments (taxes, subsidies, cap-and-trade, etc.);
- private mechanisms;
- education and awareness.

These are essential tools to guide policy in the adoption of evidence-based measures.

New and additional resources are needed to support ongoing research in ecosystem and nature-based solutions, especially blue carbon sinks (seagrass meadows, marshes, etc.), to promote sustainable development pathways, especially through the following activities:

- conservation;
- management;
- restoration.

In this sense, improving coordination and cooperation between Mediterranean countries and actors would be vital to advance knowledge in an area that both supports and provides livelihoods in many Mediterranean coastal areas.

References

Aguilera E., Díaz-Gaona C., García-Laureano R., Reyes-Palomo C., Guzmán G. I., Ortolani L., Sánchez-Rodríguez M., and Rodríguez-Estévez V. (2020). Agroecology for adaptation to climate change and resource depletion in the Mediterranean region. A review. *Agricultural Systems*, *181*, 102809. doi: 10.1016/j.agsy.2020.102809

Ali E., Cramer W., Carnicer J., Georgopoulou E., Hilmi N. J. M., Le Cozannet G., and Lionello P. (2022). Cross-Chapter Paper 4: Mediterranean Region. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2233–2272. doi: 10.1017/9781009325844.021

Al-Jawaldeh A., Nabhani M., Taktouk M., and Nasreddine L. (2022). Climate Change and Nutrition: Implications for the Eastern Mediterranean Region. *International Journal of Environmental Research and Public Health*, *19*(24), 17086. doi: 10.3390/ijerph192417086

Alvaredo F., Assouad L., and Piketty T. (2019). Measuring Inequality in the Middle East 1990–2016: The World's Most Unequal Region? *Review of Income and Wealth*, *65*(4), 685–711. doi: 10.1111/roiw.12385

Alvaredo F., Piketty T., and Oxford E. (2014). *Measuring top incomes and inequality in the Middle East: data limitations and illustration with the case of Egypt*. CEPR Discussion Paper No. DP10068. https://ssrn.com/abstract=2501542

Analitis A., Katsouyanni K., Biggeri A., Baccini M., Forsberg B., Bisanti L., Kirchmayer U., Ballester F., Cadum E., Goodman P. G., Hojs A., Sunyer J., Tiittanen P., and Michelozzi P. (2008). Effects of Cold Weather on Mortality: Results From 15 European Cities Within the PHEWE Project. *American Journal of Epidemiology*, *168*(12), 1397–1408. doi: 10.1093/aje/kwn266

Antonelli M., Billard G., Boucher J., Dessì A., Fattibene D., Franza L., Fusco F., and Jaafar H. (2021). *Climate Change and Sustainability: Mediterranean Perspectives* (A. Dessì, D. Fattibene, & F. Fusco, Eds.). Rome, Nuova Cultura, 135 pp. https://www.iai.it/en/pubblicazioni/c02/climate-change-and-sustainability-mediterranean-perspectives

Asero V., and Skonieczny S. (2018). Cruise Tourism and Sustainability in the Mediterranean. Destination Venice. In L. Butowski (Ed.), *Mobilities, Tourism and Travel Behavior - Contexts and Boundaries*. InTech. doi: 10.5772/intechopen.71459

Assa J., and Calderon C. (2020). Privatization and Pandemic: A Cross-Country Analysis of COVID-19 Rates and Health-Care Financing Structures. *Res Gate 2008*, 1–23. doi :10.13140/rg.2.2.19140.65929

Atteridge A., and Remling E. (2018). Is adaptation reducing vulnerability or redistributing it? *WIREs Climate Change*, *9*(1), e500. doi: 10.1002/wcc.500

Aurelle D., Thomas S., Albert C., Bally M., Bondeau A., Boudouresque C., Cahill A. E., Carlotti F., Chenuil A., Cramer W., Davi H., De Jode A., Ereskovsky A., Farnet A., Fernandez C., Gauquelin T., Mirleau P., Monnet A., Prévosto B., … Fady B. (2022). Biodiversity, climate change, and adaptation in the Mediterranean. *Ecosphere*, *13*(4), e3915. doi: 10.1002/ecs2.3915

Bartoletto S. (2020). *Energy Transitions in Mediterranean Countries*. Edward Elgar Publishing, Cheltenham-Northampton, UK-USA. doi: 10.4337/9781788977555

Becken S. (2010). *The Importance of Climate and Weather for Tourism: Literature Review*. Lincoln University. LEaP, Lincoln, Canterbury. https://hdl.handle.net/10182/2920

Becken S., and Hay J. (2007). Tourism and Climate Change. Risks and Opportunities. In *Climate Change and Tourism: From Policy to Practice*. Clevedon: Channelview Publications, 307 pp. doi: 10.4324/9780203128961

Bellon M., and Massetti E. (2022). Economic Principles for Integrating Adaptation to Climate Change into Fiscal Policy. *Staff Climate Notes*, *2022*(001). doi: 10.5089/9781513592374.066

Ben Jannet Allal H., Guarrera L., Karbuz S., Menichetti E., Lescoeur B., El Agrebi H., Harrouch H., Campana D., Greaume F., Bedes C., Bolinches C., Meraud T., Tappero D., Bosseboeuf D., Lechevin B., Abaach H., Damasiotis M., Darras M., Hajjaji M., … Osman N. (2016). *Mediterranean energy transition: 2040 scenario Executive summary*. https://inis.iaea.org/records/md9ba-h6417

Bertram C., Quaas M., Reusch T. B. H., Vafeidis A. T., Wolff C., and Rickels W. (2021). The blue carbon wealth of nations. *Nature Climate Change 11*(8), 704–709. doi: 10.1038/s41558-021-01089-4

Bocci M., Murciano C., and Grimes S. (2018). *Climate Change Impact on the Tourism Sector in the Southern Mediterranean. Foreseen Developments and Policy Measures. Final Report* (European Commission & Secretariat of the Union for the Mediterranean, Eds.). Secretariat of the Union for the Mediterranean, Barcelona, Spain. https://ufmsecretariat.org/wp-content/uploads/2018/11/UfMReport_ClimateChangeAndTourism.pdf

Boudouresque C. F., Bernard G., Pergent G., Shili A., and Verlaque M. (2009). Regression of Mediterranean seagrasses caused by natural processes and anthropogenic disturbances and stress: a critical review. *Botanica Marina*, *52*(5), 395–418. doi : 10.1515/bot.2009.057

Boyd D., Pathak M., van Diemen R., and Skea J. (2022). Mitigation co-benefits of climate change adaptation: A case-study analysis of eight cities. *Sustainable Cities and Society*, *77*, 103563. doi :10.1016/j.scs.2021.103563

Bräuninger M., Butzengeiger-Geyer S., Dlugolecki A., Hochrainer S., Köhler M., Linnerooth-Bayer J., Mechler R., Michaelowa A., and Schulze S. (2011). *Application of economic instruments for adaptation to climate change Final report*. https://climate.ec.europa.eu/system/files/2016-11/economic_instruments_en.pdf

Bray L., Reizopoulou S., Voukouvalas E., Soukissian T., Alomar C., Vázquez-Luis M., Deudero S., Attrill M., and Hall-Spencer J. (2016). Expected Effects of Offshore Wind Farms on Mediterranean Marine Life. *Journal of Marine Science and Engineering*, *4*(1), 18. doi: 10.3390/jmse4010018

Briguglio L. P. (2016). Exposure to external shocks and economic resilience of countries: evidence from global indicators. *Journal of Economic Studies*, *43*(6), 1057–1078. doi: 10.1108/jes-12-2014-0203

Briguglio M., and Moncada S. (2020). *Malta, COVID-19 Island Insight Series, no 1, November 2020*. University of Strathclyde Centre for Environmental Law and Governance, University of Prince Edward Island Institute of Island Studies and Island Innovation, 1-6. https://www.um.edu.mt/library/oar/handle/123456789/63472

Capasso R., Zurlo M. C., and Smith A. P. (2018). Stress in Factory Workers in Italy: An Application of the Ethnicity and Work-related Stress Model in Moroccan Factory Workers. *Psychology and Developing Societies*, *30*(2), 199–233. doi: 10.1177/0971333618783397

CEB (2020). *Technical Brief, Investing in inclusive, resilient and sustainable social infrastructure in Europe: the CEB's experience*.Available at www.coebank.org.

Chefaoui R. M., Duarte C. M., and Serrão E. A. (2018). Dramatic loss of seagrass habitat under projected climate change in the Mediterranean Sea. *Global Change Biology*, *24*(10), 4919–4928. https://doi.org/10.1111/gcb.14401

Cinner J. E., Adger W. N., Allison E. H., Barnes M. L., Brown K., Cohen P. J., Gelcich S., Hicks C. C., Hughes T. P., Lau J., Marshall N. A., and Morrison T. H. (2018). Building adaptive capacity to climate change in tropical coastal communities. *Nature Climate Change*, *8*(2), 117–123. doi: 10.1038/s41558-017-0065-x

Ciriminna R., Albanese L., Pecoraino M., Meneguzzo F., and Pagliaro M. (2019). Solar Energy and New Energy Technologies for Mediterranean Countries. *Global Challenges*, *3*(10), 1900016. doi: 10.1002/gch2.201900016

CLIA (2022). *State of the cruise industry. Outlook*. https://cruising.org/sites/default/files/2025-03/CLIA-State-Of-The-Cruise-Industry-2022_updated.pdf

CLIA (2023). *2023 Global Passenger Report*. https://cruising.org/resources/2023-global-passenger-report

Climate Policy Initiative (2021). *Global Landscape of Climate Finance 2021*. https://www.climatepolicyinitiative.org/wp-content/uploads/2021/10/Full-report-Global-Landscape-of-Climate-Finance-2021.pdf

Cofala J., Amann M., Borken-Kleefeld J., Gomez Sanabria A., Heyes C., Kiesewetter G., Sander R., Schöpp W., Holland M., Fagerli H., and Nyiri A. (2018). *The potential for cost-effective air emission reductions from international shipping through designation of further Emission Control Areas in EU waters with focus on the Mediterranean Sea. Final Report*. IIASA Research Report. Laxenburg, Austria: RR-18-002. https://pure.iiasa.ac.at/15729

Coll M., Piroddi C., Steenbeek J., Kaschner K., Lasram F. B. R., Aguzzi J., Ballesteros E., Bianchi C. N., Corbera J., Dailianis T., Danovaro R., Estrada M., Froglia C., Galil B. S., Gasol J. M., Gertwage R., Gil J., Guilhaumon F., Kesner-Reyes K., … Voultsiadou E. (2010). The biodiversity of the Mediterranean Sea: Estimates, patterns, and threats. *PLoS ONE*, *5*(8), e11842. doi: 10.1371/journal.pone.0011842

Conde-Sala J. L., Portellano-Ortiz C., Calvó-Perxas L., and Garre-Olmo J. (2017). Quality of life in people aged 65+ in Europe: associated factors and models of social welfare—analysis of data from the SHARE project (Wave 5). *Quality of Life Research*, *26*(4), 1059–1070. doi: 10.1007/s11136-016-1436-x

Costa C., Fosse J., and Approual A. (2022). *Financing the sustainable development of the Mediterranean: What role for Green and climate finance?* IEMed., Barcelona, Spain. https://www.iemed.org/wp-content/uploads/2022/04/ThefutureGreenClimateFinanceMed_05-DSI-ECO-Union.pdf

Cramer W., Guiot J., Fader M., Garrabou J., Gattuso J.-P., Iglesias A., Lange M. A., Lionello P., Llasat M. C., Paz S., Peñuelas J., Snoussi M., Toreti A., Tsimplis M. N., and Xoplaki E. (2018). Climate change and interconnected risks to sustainable development in the Mediterranean. *Nature Climate Change*, *8*(11), 972–980. doi: 10.1038/s41558-018-0299-2

Dasgupta P. S., and Heal G. M. (1980). *Economic Theory and Exhaustible Resources*. Cambridge: Cambridge University Press. doi: 10.1017/cbo9780511628375

De Bel-Air F. (2016). Gulf and EU migration policies after the Arab Uprisings: Arab and Turkish youth as a security issue. In *Power2Youth Papers*. (Issue 7). Roma, IAI, February 2016, 40 pp. https://www.iai.it/en/pubblicazioni/c34/gulf-and-eu-migration-policies-after-arab-uprisings

Demaria F., Schneider F., Sekulova F., and Martinez-Alier J. (2013). What is Degrowth? From an Activist Slogan to a Social Movement. *Environmental Values*, *22*(2), 191–215. doi: 10.3197/096327113x13581561725194

Deng H.-M., Liang Q.-M., Liu L.-J., and Anadon L. D. (2017). Co-benefits of greenhouse gas mitigation: a review and classification by type, mitigation sector, and geography. *Environmental Research Letters*, *12*(12), 123001. doi: 10.1088/1748-9326/aa98d2

Di Bartolomeo A., Gabrielli G., and Strozza S. (2015). *The Migration and Integration of Moroccan and Ukrainian migrants in Italy: Policies and Measures*. Policy Centre, INTERACT Research Report, Corridor Report. https://hdl.handle.net/1814/35880

Dierschke V., Furness R. W., and Garthe S. (2016). Seabirds and offshore wind farms in European waters: Avoidance and attraction. *Biological Conservation*, *202*, 59–68. doi: 10.1016/j.biocon.2016.08.016

Diffenbaugh N. S., and Burke M. (2019). Global warming has increased global economic inequality. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(20), 9808–9813. doi: 10.1073/pnas.1816020116

dos Santos M., Moncada S., Elia A., Grillakis M., and Hilmi N. (2020). Society: Development. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report*. Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, pp. 469-492. doi: 10.5281/zenodo.7101111

Drius M., Bongiorni L., Depellegrin D., Menegon S., Pugnetti A., and Stifter S. (2019). Tackling challenges for Mediterranean sustainable coastal tourism: An ecosystem service perspective. *Science of The Total Environment*, *652*, 1302–1317. doi: 10.1016/j.scitotenv.2018.10.121

Drobinski P., Azzopardi B., Ben Janet Allal H., Bouchet V., Civel E., Creti A., Duic N., Fylaktos N., Mutale J., Pariente-David S., Ravetz J., Taliotis C., and Vautard R. (2020). Energy transition in the Mediterranean. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report*. Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, pp. 265-322. doi: 10.5281/zenodo.7101088

EC Secretariat-General (2019). *European Green Deal. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions — The European Green Deal (COM(2019) 640 final, 11.12.2019).* doi: 10.2775/373022

EIU (2022). *Global Liveability Index*. The Economist Intelligence Unit Limited. https://www.eiu.com/n/wp-content/uploads/2022/07/liveability-index-2022.pdf

EMN (2021). *Statistical Annex of the 'Annual Report on Migration and Asylum 2020'*. Directorate General for Migration and Home Affairs, European Commission. https://www.emn.at/wp-content/uploads/2020/12/emn-arm-2020-statistical-annex.pdf

Enrichetti F., Bava S., Bavestrello G., Betti F., Lanteri L., and Bo M. (2019). Artisanal fishing impact on deep coralligenous animal forests: A Mediterranean case study of marine vulnerability. *Ocean & Coastal Management*, *177*, 112–126. doi: 10.1016/j.ocecoaman.2019.04.021

Eriksen S., Aldunce P., Bahinipati C. S., Martins R. D., Molefe J. I., Nhemachena C., O'Brien K., Olorunfemi F., Park J., Sygna L., and ULSRUD K. (2011). When not every response to climate change is a good one: Identifying principles for sustainable adaptation. *Climate and Development*, *3*(1), 7–20. doi: 10.3763/cdev.2010.0060

European Investment Bank (2008). *Facility for Euro-Mediterranean Investment and Partnership. Study on Climate Change and Energy in the Mediterranean.* https://www.eib.org/files/publications/country/climate_change_energy_mediterranean_en.pdf

FAO (2020). *The State of Mediterranean and Black Sea Fisheries 2020. General Fisheries Commission for the Mediterranean*. FAO, Rome. doi: 10.4060/cb2429en

FAO (2023). The status of women in agrifood systems. In *The status of women in agrifood systems*. FAO, Rome, Italy. doi: 10.4060/cc5343en

FAO, and Plan Bleu (2018). *State of Mediterranean Forests 2018*. Food and Agriculture Organization of the United Nations, Rome and Plan Bleu, Marseille.

Feleki E., and Moussiopoulos N. (2021). Setting Emission Reduction Trajectories in Mediterranean Cities with the Use of Science-Based Targets: The Pathway towards Climate Neutrality and the Ambitious European Goals by 2050. *Atmosphere*, *12*(11), 1505. doi: 10.3390/atmos12111505

Filho W. L., Barbir J., Sima M., Kalbus A., Nagy G. J., Paletta A., Villamizar A., Martinez R., Azeiteiro U. M., Pereira M. J., Mussetta P. C., Ivars J. D., Salgueirinho Osório de Andrade Guerra J. B., de Silva Neiva S., Moncada S., Galdies C., Klavins M., Nikolova M., Gogu R. C., … Bonoli A. (2020). Reviewing the role of ecosystems services in the sustainability of the urban environment: A multi-country analysis. *Journal of Cleaner Production*, *262*, 121338. doi: 10.1016/j.jclepro.2020.121338

Fraga H., Moriondo M., Leolini L., and Santos J. A. (2020). Mediterranean Olive Orchards under Climate Change: A Review of Future Impacts and Adaptation Strategies. *Agronomy*, *11*(1), 56. doi: 10.3390/agronomy11010056

Galparsoro I., Menchaca I., Garmendia J. M., Borja Á., Maldonado A. D., Iglesias G., and Bald J. (2022). Reviewing the ecological impacts of offshore wind farms. *Npj Ocean Sustainability*, *1*(1). doi: 10.1038/s44183-022-00003-5

Geissdoerfer M., Savaget P., Bocken N. M. P., and Hultink E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. doi: 10.1016/j.jclepro.2016.12.048

Giordano L., Portacci G., and Caroppo C. (2019). Multidisciplinary tools for sustainable management of an ecosystem service: The case study of mussel farming in the Mar Piccolo of Taranto (Mediterranean, Ionian Sea). *Ocean & Coastal Management*, *176*, 11–23. doi: 10.1016/j.ocecoaman.2019.04.013

Gómez Martín M. B. (2005). Weather, climate and tourism a geographical perspective. *Annals of Tourism Research*, *32*(3), 571–591. doi: 10.1016/j.annals.2004.08.004

Gürlük S. (2009). Economic growth, industrial pollution and human development in the Mediterranean Region. *Ecological Economics*, *68*(8–9), 2327–2335. doi: 10.1016/j.ecolecon.2009.03.001

Hallegatte S., and Rozenberg J. (2017). Climate change through a poverty lens. *Nature Climate Change*, *7*(4), 250–256. doi: 10.1038/nclimate3253

Hendriks I. E., Escolano-Moltó A., Flecha S., Vaquer-Sunyer R., Wesselmann M., and Marbà N. (2022). Mediterranean seagrasses as carbon sinks: methodological and regional differences. *Biogeosciences*, *19*, 4619–4637. doi: 10.5194/bg-19-4619-2022

Hickel J. (2017). Is global inequality getting better or worse? A critique of the World Bank's convergence narrative. *Third World Quarterly*, *38*(10), 2208–2222. doi: 10.1080/01436597.2017.1333414

Hong H., Karolyi G. A., and Scheinkman J. A. (2020). Climate Finance. *The Review of Financial Studies*, *33*(3), 1011–1023. doi: 10.1093/rfs/hhz146

Howitt O. J. A., Revol V. G. N., Smith I. J., and Rodger C. J. (2010). Carbon emissions from international cruise ship passengers' travel to and from New Zealand. *Energy Policy*, *38*(5), 2552–2560. doi: 10.1016/j.enpol.2009.12.050

Iglesias A., and Garrote L. (2015). Adaptation strategies for agricultural water management under climate change in Europe. *Agricultural Water Management*, *155*, 113–124. doi: 10.1016/j.agwat.2015.03.014

Iglesias A., Santillán D., and Garrote L. (2018). On the Barriers to Adaption to Less Water under Climate Change: Policy Choices in Mediterranean Countries. *Water Resources Management*, *32*(15), 4819–4832. doi: 10.1007/s11269-018-2043-0

ILO (2016). *World Employment and Social Outlook 2016: Trends for youth*. International Labour Organization, Geneva. https://digitallibrary.un.org/record/4034748?v=pdf

IMO (2022). *Identification and Protection of Special Areas, ECAS and PSSAs Proposal to Designate the Mediterranean Sea, as a whole, as an Emission Control Area for Sulphur Oxides*. https://cleanarctic.org/wp-content/uploads/2022/06/MEPC-78-11-Proposal-to-Designate-the-Mediterranean-Sea-as-a-whole-as-an-Emission-ControlArea-for-Su...-Albania-Algeria-Austria....pdf

IPCC (2019). *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* (H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N. M. Weyer, Eds.). Cambridge University Press, Cambridge, UK and New York, NY, USA, 755 pp. doi: 10.1017/9781009157964

IPCC (2022a). Annex I: Glossary [van Diemen, R., J.B.R. Matthews, V. Möller, J.S. Fuglestvedt, V. Masson-Delmotte, C. Méndez, A. Reisinger, S. Semenov (eds)]. In R. van Diemen, J. B. R. Matthews, V. Möller, J. S. Fuglestvedt, V. Masson-Delmotte, C. Méndez, A. Reisinger, & S. Semenov (Eds.), *IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.020

IPCC (2022b). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama, Eds.). Cambridge University Press. Cambridge, UK and New York, NY, USA, 3056 pp. doi: 10.1017/9781009325844

IPCC (2022c). *Climate Change 2022: Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley, Eds.). Cambridge University Press. Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926

IRENA (2014). *Pan-Arab Strategy for the Development of Renewable Energy Applications: 2010-2030*. IRENA in collaboration with the League of Arab States, and produced by RCREEE. https://www.irena.org/publications/2014/Jun/Pan-Arab-Renewable-Energy-Strategy-2030-Roadmap-of-Actions-for-Implementation

IRENA (2021a). *Renewable Energy Statistics 2021*. International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/publications/2021/Aug/Renewable-energy-statistics-2021

IRENA (2021b). *Renewables Readiness Assessment: Albania*. International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/publications/2021/March/Renewables-Readiness-Assessment-Albania

IRENA (2023). *Renewables Readiness Assessment: Bosnia and Herzegovina*. International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/Publications/2023/Sep/Renewables-Readiness-Assessment-Bosnia-and-Herzegovina

IRENA, and IEA-PVPS (2018). *End of life management solar photovoltaic panels* (Issue June 2016). International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/publications/2016/Jun/End-of-life-management-Solar-Photovoltaic-Panels

Johansson-Stenman O. (1998). The Importance of Ethics in Environmental Economics with a Focus on Existence Values. *Environmental and Resource Economics*, *11*(3), 429–442. doi: 10.1023/a:1008239427421

Jones P., Hillier D., and Comfort D. (2016). The Environmental, social and economic impacts of cruising and corporate sustainability strategies. *Athens Journal of Tourism*, *3*(4), 273–285. doi: 10.30958/ajt.3-4-2

Karanasiou A. P. (2021). *Cruise shipping and emissions in Mediterranean ports (Doctoral dissertation)*. University of Piraeus (Greece).

Katircioglu S., Cizreliogullari M. N., and Katircioglu S. (2019). Estimating the role of climate changes on international tourist flows: evidence from Mediterranean Island States. *Environmental Science and Pollution Research*, *26*(14), 14393–14399. doi: 10.1007/s11356-019-04750-w

Koopmans D., Holtappels M., Chennu A., Weber M., and de Beer D. (2020). High net primary production of Mediterranean seagrass (Posidonia oceanica) meadows determined with aquatic eddy covariance. *Frontiers in Marine Science*, *7*, 496010. doi: 10.3389/fmars.2020.00118

Kougias I., Aggidis G., Avellan F., Deniz S., Lundin U., Moro A., Muntean S., Novara D., Pérez-Díaz J. I., Quaranta E., Schild P., and Theodossiou N. (2019). Analysis of emerging technologies in the hydropower sector. *Renewable and Sustainable Energy Reviews*, *113*, 109257. doi: 10.1016/j.rser.2019.109257

Kourantidou M., Cuthbert R. N., Haubrock P. J., Novoa A., Taylor N. G., Leroy B., Capinha C., Renault D., Angulo E., Diagne C., and Courchamp F. (2021). Economic costs of invasive alien species in the Mediterranean basin. *NeoBiota*, *67*, 427–458. doi: 10.3897/neobiota.67.58926

Kulovesi K., and Oberthür S. (2020). Assessing the EU's 2030 Climate and Energy Policy Framework: Incremental change toward radical transformation? *Review of European, Comparative & International Environmental Law*, *29*(2), 151–166. doi: 10.1111/reel.12358

Layard R. (2011). *Happiness: Lessons from a New Science (Second Edition)*. Penguin UK, 384 pp.

Lehndorff S. (2012). *A triumph of failed ideas: European models of capitalism in the crisis*. ETUI, The European Trade Union Institute. https://www.etui.org/publications/books/a-triumph-of-failed-ideas-european-models-of-capitalism-in-the-crisis

Linares C., Díaz J., Negev M., Martínez G. S., Debono R., and Paz S. (2020). Impacts of climate change on the public health of the Mediterranean Basin population - Current situation, projections, preparedness and adaptation. *Environmental Research*, *182*, 109107. doi: 10.1016/j.envres.2019.109107

Lionello P., Barriopedro D., Ferrarin C., Nicholls R. J., Orlić M., Raicich F., Reale M., Umgiesser G., Vousdoukas M., and Zanchettin D. (2021). Extreme floods of Venice: characteristics, dynamics, past and future evolution (review article). *Natural Hazards and Earth System Sciences*, *21*(8), 2705–2731. doi: 10.5194/nhess-21-2705-2021

Lloret J., Turiel A., Solé J., Berdalet E., Sabatés A., Olivares A., Gili J.-M., Vila-Subirós J., and Sardá R. (2022). Unravelling the ecological impacts of large-scale offshore wind farms in the Mediterranean Sea. *Science of The Total Environment*, *824*, 153803. doi: 10.1016/j.scitotenv.2022.153803

MacNeill T., and Wozniak D. (2018). The economic, social, and environmental impacts of cruise tourism. *Tourism Management*, *66*, 387–404. doi: 10.1016/j.tourman.2017.11.002

Maggio A., De Pascale S., Fagnano M., and Barbieri G. (2011). Saline agriculture in Mediterranean environments. *Italian Journal of Agronomy*, *6*(1), 7. doi: 10.4081/ija.2011.e7

Magnan A., Hamilton J., Rosselló J., Billé R., and Bujosa A. (2013). Mediterranean Tourism and Climate Change: Identifying Future Demand and Assessing Destinations' Vulnerability. In A. Navarra & L. Tubiana (Eds.), *Regional Assessment of Climate Change in the Mediterranean. Advances in Global Change Research, vol 51*. Springer, Dordrecht. doi: 10.1007/978-94-007-5772-1_15

Manera C., Garau J., and Serrano E. (2016). The evolution and impact of tourism in the Mediterranean: the case of Island Regions, 1990-2002. *Cuadernos de Turismo*, *37*, 269. doi: 10.6018/turismo.37.256241

Mavraki N., Degraer S., Vanaverbeke J., and Braeckman U. (2020). Organic matter assimilation by hard substrate fauna in an offshore wind farm area: a pulse-chase study. *ICES Journal of Marine Science*, *77*(7–8), 2681–2693. doi: 10.1093/icesjms/fsaa133

McAuliffe M., and Triandafyllidou A. (2021). World Migration Report 2022. In M. McAuliffe & A. Triandafyllidou (Eds.), *World Migration Report 2022*. International Organization for Migration (IOM), Geneva. https://publications.iom.int/books/world-migration-report-2022

Mcleod E., Chmura G. L., Bouillon S., Salm R., Björk M., Duarte C. M., Lovelock C. E., Schlesinger W. H., and Silliman B. R. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Frontiers in Ecology and the Environment*, *9*(10), 552–560. doi: 10.1890/110004

Meadows D. H., Meadows D. L., Randers J., and Behrens W. W. (1972). The Limits to Growth, Club of Rome. In *New York, Universe*. New York, Universe Books. https://www.clubofrome.org/publication/the-limits-to-growth/

Mebratu D. (1998). Sustainability and sustainable development. *Environmental Impact Assessment Review*, *18*(6), 493–520. doi: 10.1016/s0195-9255(98)00019-5

MedCruise (2017). *Cruise Activities in MedCruise Ports 2017 STATISTICS*. MedCruise, Piraeus, Greece, 78 pp. https://www.medcruise.com/2017-statistics

MedECC (2020a). *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report* (W. Cramer, J. Guiot, & K. Marini, Eds.). Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, 632 pp. doi: 10.5281/zenodo.4768833

MedECC (2020b). Summary for Policymakers. In W. Cramer, J. Guiot, & K. Marini (Eds.), *Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report*. Union for the Mediterranean, Plan Bleu, UNEP/ MAP, Marseille, France, pp 11-40. doi: 10.5281/zenodo.5513887

Mejjad N., Rossi A., and Pavel A. B. (2022). The coastal tourism industry in the Mediterranean: A critical review of the socio-economic and environmental pressures & impacts. *Tourism Management Perspectives*, *44*, 101007. doi: 10.1016/j.tmp.2022.101007

Midgley A., Tanganelli K., Henders S., Tippmann R., and Agoumi A. (2018). *International Public Climate Finance in the Mediterranean*. Luxembourg: Publications Office of the European Union. https://ufmsecretariat.org/wp-content/uploads/2018/12/UfM-Climate-Finance-Study-2018.pdf

Milovanoff A., Posen I. D., and MacLean H. L. (2020). Electrification of light-duty vehicle fleet alone will not meet mitigation targets. *Nature Climate Change*, *10*(12), 1102–1107. doi: 10.1038/s41558-020-00921-7

Moncada S., and Randall J. E. (2022). Progress and success by sovereignty? The attainment of the sustainable development goals in small island states, small island developing states, and subnational island jurisdictions. In J. E. Randall (Ed.), *Annual Report on Global Islands 2021 (pp. 85-105)*. Charlottetown: Islands Studies Press. https://www.um.edu.mt/library/oar/handle/123456789/118270

Moreno-Dodson B., Pariente-David S., and Tsakas C. (2021). *A Mediterranean Green Deal for an Effective Energy Transition as Part of The Sustainable Post-COVID recovery*. CMI, Marseille. https://www.iemed.org/wp-content/uploads/2022/06/Clean-Energy-Challenges-Euro-Mediterranean-Region-Moreno-Dodson-Tsakas-Pariente-IEMedYearbook2022.pdf

Murphy E. (2018). The In-securitisation of Youth in the South and East Mediterranean. *The International Spectator*, *53*(2), 21–37. doi: 10.1080/03932729.2018.1454084

NRDC (2021). *Paris Climate Agreement: Everything You Need to Know*. https://www.nrdc.org/stories/paris-climate-agreement-everything-you-need-know

OECD (2021). *OECD Implementation Handbook for Quality Infrastructure Investment: Supporting a Sustainable Recovery from the COVID-19 Crisis*. OECD Publishing, Paris. doi: 10.1787/479131b2-en

OECD (2016). *The Ocean Economy in 2030*. OECD Publishing, Paris. doi: 10.1787/9789264251724-en

OECD (2020). *A Territorial Approach to the Sustainable Development Goals: Synthesis report*. OECD Urban Policy Reviews, OECD Publishing, Paris. doi: 10.1787/e86fa715-en

OECD-DAC (2006). *The challenge of capacity development: working towards good practice*. Paris: OECD. Available at www.oecd.org.

OME (2022). *Mediterranean Energy Perspectives 2022 – Special COP27 edition*. Organisation Méditerranéenne de l'Energie et du Climat, Paris. https://www.omec-med.org/mep-2022-special-cop27-edition-released-in-december-2022/

One Planet Sustainable Tourism Programme (2021). *Glasgow Declaration: a Commitment to a Decade of Climate Actio*. https://www.oneplanetnetwork.org/sites/default/files/2022-02/GlasgowDeclaration_EN_0.pdf

Pallis A. A. (2015). *Cruise Shipping and Urban Development: State of the Art of the Industry and Cruise Ports*. https://www.oecd-ilibrary.org/transport/cruise-shipping-and-urban-development_5jrvzrlw74nv-en

Pallis, T. (2015) Cruise Shipping and Urban Development: State of the Art of the Industry and Cruise Ports, *International Transport Forum Discussion Papers,* No. 2015/14. OECD Publishing, Paris. doi: 10.1787/5jrvzrlw74nv-en

Panayotou T., and UNEP Environment and Economics Unit. (1994). Economic instruments for environmental management and sustainable development. In *Consultative Expert Group Meeting on the Use and Application of Economic Policy Instruments for Environmental Management and Sustainable Development.* Nairobi: UNEP, 108 pages. https://digitallibrary.un.org/record/276346

Petrișor A.-I., Hamma W., Nguyen H. D., Randazzo G., Muzirafuti A., Stan M.-I., Tran V. T., Aștefănoaiei R., Bui Q.-T., Vintilă D.-F., Truong Q. H., Lixăndroiu C., Țenea D.-D., Sîrodoev I., and Ianoș I. (2020). Degradation of Coastlines under the Pressure of Urbanization and Tourism: Evidence on the Change of Land Systems from Europe, Asia and Africa. *Land*, *9*(8), 275. doi: 10.3390/land9080275

Piante C., and Ody D. (2015). *Blue Growth in the Mediterranean Sea: the Challenge of Good Environmental Status.* MedTrends Project. WWF-France. 192 pages.

Pisacane G., Sannino G., Carillo A., Struglia M. V., and Bastianoni S. (2018). Marine Energy Exploitation in the Mediterranean Region: Steps Forward and Challenges. *Frontiers in Energy Research*, *6*. doi: 10.3389/fenrg.2018.00109

Plan Bleu (2022a). *Guidelines for the sustainability of cruises and recreational boating in the Mediterranean region*. Interreg MED Blue Growth Community project. https://planbleu.org/en/publications/guidelines-for-the-sustainability-of-cruising-and-recreational-boating-in-the-mediterranean-region/

Plan Bleu (2022b). *State of Play of Tourism in the Mediterranean*. Interreg Med Sustainable Tourism Community project. https://planbleu.org/en/publications/state-of-play-of-tourism-in-the-mediterranean/

Plan Bleu (2022c). *Towards Sustainable Development of Marine Renewable Energies in the Mediterranean, Interreg MED Blue Growth Community project* (Plan Bleu - Regional Activity Centre of UNEP/MAP, Ed.). Plan Bleu - Regional Activity Centre of UNEP/MAP, Marseille, France. https://planbleu.org/en/publications/towards-a-sustainable-development-of-marine-renewable-energy-in-the-mediterranean/

Plan Bleu, and EIB (2008). *Climate Change and Energy in the Mediterranean*. https://www.eib.org/files/publications/country/climate_change_energy_mediterranean_en.pdf

Prakash A., Conde C., Ayanlade A., Kerr R. B., Boyd E., Caretta M. A., Clayton S., Rivera Ferre M. G., Gallardo L. R., Halim S. A., Lansbury N., Lipka O., Morgan R., Roy J., Reckien D., Schipper E. L. F., Singh C., Tirado von der Pahlen M. C., Totin E., ... Zaiton Ibrahim Z. (2022). Cross-Chapter Box GENDER | Gender, Climate Justice and Transformative Pathways. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2700–2704. https://www.ipcc.ch/report/ar6/wg2/chapter/chapter-18/

Purvis B., Mao Y., and Robinson D. (2019). Three pillars of sustainability: in search of conceptual origins. *Sustainability Science*, *14*, 681–695. doi: 10.1007/s11625-018-0627-5

Randone M., Di Carlo G., Costantini M., Tzanetti T., Haferkamp D., Portafaix A., Smits M., Antoniades V., Kachaner N., and Osborne A. (2017). Reviving the economy of the Mediterranean Sea: actions for a sustainable future. In *WWF Mediterranean Marine Initiative, Rome, Italy*. WWF Mediterranean Marine Initiative, Rome, Italy. https://wwfeu.awsassets.panda.org/downloads/reviving_mediterranean_sea_economy_full_rep_lowres.pdf

Reckien D., Buzasi A., Olazabal M., Spyridaki N.-A., Eckersley P., Simoes S. G., Salvia M., Pietrapertosa F., Fokaides P., Goonesekera S. M., Tardieu L., Balzan M. V., de Boer C. L., De Gregorio Hurtado S., Feliu E., Flamos A., Foley A., Geneletti D., Grafakos S., … Wejs A. (2023a). Quality of urban climate adaptation plans over time. *Npj Urban Sustainability*, *3*(1), 13. doi: 10.1038/s42949-023-00085-1

Reckien D., Magnan A. K., Singh C., Lukas-Sithole M., Orlove B., Schipper E. L. F., and Coughlan de Perez E. (2023b). Navigating the continuum between adaptation and maladaptation. *Nature Climate Change*, *13*(9), 907–918. doi: 10.1038/s41558-023-01774-6

Reimann L., Merkens J. L., and Vafeidis A. T. (2018). Regionalized Shared Socioeconomic Pathways: narratives and spatial population projections for the Mediterranean coastal zone. *Regional Environmental Change*, *18*(1), 235-245. doi: 10.1007/s10113-017-1189-2

Ross F. (2019). Kate Raworth - Doughnut Economics: Seven Ways to Think Like a 21st Century Economist (2017). *Regional and Business Studies*, *11*(2), 81-86. doi: 10.33568/rbs.2409

Sachs J. D., Kroll C., Lafortune G., Fuller G., and Woelm F. (2021). *The Decade of Action for the Sustainable Development Goals: Sustainable Development Report 2021*. Cambridge: Cambridge University Press. https://sdgtransformationcenter.org/reports/sustainable-development-report-2021

Sachs J. D., Lafortune G., Kroll C., Fuller G., and Woelm F. (2022). *From Crisis to Sustainable Development: the SDGs as Roadmap to 2030 and Beyond. Sustainable Development Report 2022*. Cambridge: Cambridge University Press. https://sdgtransformationcenter.org/reports/sustainable-development-report-2022

Sachs J. D., Schmidt-Traub G., Kroll C., Lafortune G., Fuller G., and Woelm F. (2020). *Sustainable Development Report 2020*. Cambridge: Cambridge University Press. https://sdgtransformationcenter.org/reports/sustainable-development-report-2020

Sachs J. D., Schmidt-Traub G., Mazzucato M., Messner D., Nakicenovic N., and Rockström J. 2019a. Six Transformations to achieve the Sustainable Development Goals. *Nature Sustainability*, *2*(9), 805–814. doi: 10.1038/s41893-019-0352-9

Sachs J. D., Schmidt-Traub G., Pulselli R. M., Gigliotti M., Cresti S., and Riccaboni A. 2019b. *Sustainable Development Report 2019 – Mediterranean Countries Edition*. Siena: Sustainable Development Solutions Network Mediterranean (SDSN Mediterranean). https://sdgtransformationcenter.org/reports/sdr-2019-mediterranean-countries

Schipper E. L. F., Revi A., Preston B. L., Carr E. R., Eriksen S. H., Fernandez-Carril L. R., Glavovic B. C., Hilmi N. J. M., Ley D., Mukerji R., Muylaert de Araujo M. S., Perez R., Rose S. K., and Singh P. K. (2022). Climate Resilient Development Pathways. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2655–2807. doi: 10.1017/9781009325844.027

Senouci R., and Taibi N.-E. (2019). Impact of the urbanization on coastal dune: case of Kharrouba, West of Algeria. *Journal of Sedimentary Environments*, *4*(1), 90–98. doi: 10.12957/jse.2019.39951

Shulla K., Voigt B.-F., Cibian S., Scandone G., Martinez E., Nelkovski F., and Salehi P. (2021). Effects of COVID-19 on the Sustainable Development Goals (SDGs). *Discover Sustainability*, *2*(1), 15. doi: 10.1007/s43621-021-00026-x

Siders A. R., Ajibade I., and Casagrande D. (2021). Transformative potential of managed retreat as climate adaptation. *Current Opinion in Environmental Sustainability*, *50*, 272–280. doi: 10.1016/j.cosust.2021.06.007

Sietsma A. J., Ford J. D., Callaghan M. W., and Minx J. C. (2021). Progress in climate change adaptation research. *Environmental Research Letters*, *16*(5), 054038 doi: 10.1088/1748-9326/abf7f3

Silver H. (2015). The Contexts of Social Inclusion. *SSRN Electronic Journal*. doi: 10.2139/ssrn.2641272

Simpson M. C., Gössling S., Scott D., Hall C. M., and Gladin E. (2008). *Climate change adaptation and miti gation in the tourism sector: frameworks, tools and practices*. UNEP, University of Oxford, UNWTO, WMO: Paris, France. https://www.unep.org/resources/report/climate-change-adaptation-and-mitigation-tourism-sector-frameworks-tools-and

Smit B., Pilifosova O., Burton I., Challenger B., Huq S., Klein R., Yohe G., Adger W., Downing T., and Harvey E. (2001). Adaptation to climate change in the context of sustainable development and equity. In J. McCarthy, O. Canziani, N. Leary, D. Dokken, & K. White (Eds.), *IPCC Climate Change 2001: Impacts, Adaptation and Vulnerability*. Cambridge University Press, Cambridge, 2001, pp. 877-912. https://www.ipcc.ch/site/assets/uploads/2018/03/wg2TARchap18.pdf

Soergel B., Kriegler E., Weindl I., Rauner S., Dirnaichner A., Ruhe C., Hofmann M., Bauer N., Bertram C., Bodirsky B. L., Leimbach M., Leininger J., Levesque A., Luderer G., Pehl M., Wingens C., Baumstark L., Beier F., Dietrich J. P., … Popp A. (2021). A sustainable development pathway for climate action within the UN 2030 Agenda. *Nature Climate Change*, *11*(8), 656–664. doi: 10.1038/s41558-021-01098-3

Soukissian T., Karathanasi F., and Axaopoulos P. (2017). Satellite-Based Offshore Wind Resource Assessment in the Mediterranean Sea. *IEEE Journal of Oceanic Engineering*, *42*(1), 73–86. doi: 10.1109/joe.2016.2565018

Spalding M. D., Ruffo S., Lacambra C., Meliane I., Hale L. Z., Shepard C. C., and Beck M. W. (2014). The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. *Ocean & Coastal Management*, *90*, 50–57. doi: 10.1016/j.ocecoaman.2013.09.007

Stolz B., Held M., Georges G., and Boulouchos K. (2021). The CO2 reduction potential of shore-side electricity in Europe. *Applied Energy*, *285*, 116425. doi: 10.1016/j.apenergy.2020.116425

Surian A., and Sciandra A. (2019). City Prosperity Index: a comparative analysis of Latin American and Mediterranean cities based on well-being and social inclusion features. In *Book of Short Papers ASA Conference 2019, Statistics for Health and Well-being* (p. 210-214). http://hdl.handle.net/11577/3340080

Tarsitano E., Calvano G., and Cavalcanti E. (2019). The Mediterranean Way a model to achieve the 2030 Agenda Sustainable Development Goals (SDGs). *Journal of Sustainable Development*, *12*(1), 108. doi: 10.5539/jsd.v12n1p108

Telesca L., Belluscio A., Criscoli A., Ardizzone G., Apostolaki E. T., Fraschetti S., Gristina M., Knittweis L., Martin C. S., Pergent G., Alagna A., Badalamenti F., Garofalo G., Gerakaris V., Louise Pace M., Pergent-Martini C., and Salomidi M. (2015). Seagrass meadows (Posidonia oceanica) distribution and trajectories of change. *Scientific Reports*, *5*(1), 12505. doi: 10.1038/srep12505

Tolentino M. (2015). El buen vivir: una via para el desarrollo. Quito. Abya-yala, 2009. In *GEOgraphia* (Vol. 17, Issue 33). Pro Reitoria de Pesquisa, Pos Graduacao e Inovacao - UFF.

Tonazzini, D., Fosse, J., Morales, E., González, A., Klarwein, S., Moukaddem, K., Louveau, O. (2019) Blue Tourism. Towards a sustainable coastal and maritime tourism in world marine regions. Eco-union, Barcelona. https://bluetourisminitiative.org/publications/blue-tourism/

Torres C., Jordà G., de Vílchez P., Vaquer-Sunyer R., Rita J., Canals V., Cladera A., Escalona J. M., and Miranda M. Á. (2021). Climate change and their impacts in the Balearic Islands: a guide for policy design in Mediterranean regions. *Regional Environmental Change*, *21*(4), 107. doi: 10.1007/s10113-021-01810-1

Torrisi G. (2009). Public infrastructure: definition, classification and measurement issues. *Economics, Management, and Financial Markets*, *4*(3), 100–124. https://mpra.ub.uni-muenchen.de/25850/

UN (1992). *Agenda 21*. United Nations Conference on Environment & Development, Rio de Janerio, Brazil, 3 to 14 June 1992. https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf

UN (2012). *The Future We Want: Outcome document of the United Nations Conference on Sustainable Development Rio de Janeiro, Brazil, 20–22 June 2012*. United Nations, Rio, Brazil. https://digitallibrary.un.org/record/3826773?ln=en&v=pdf

UN DESA (2016). *Report on the World Social Situation 2016*. United Nations, New York. https://desapublications.un.org/publications/report-world-social-situation-2016-leaving-no-one-behind-imperative-inclusive

UN General Assembly (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*. Resolution Adopted by the General Assembly on 25 September 2015, A/RES/70/1. [New York]: UN, 21 Oct. 2015. https://docs.un.org/en/A/RES/70/1

UNDP (2015). *Support Capacity Development: The UNDP Approach*. UNDP, New York. https://www.undp.org/publications/support-capacity-development-undp-approach

UNDP (2022). *Human Development Report 2021-22: Uncertain Times, Unsettled Lives: Shaping our Future in a Transforming World.* New York. https://hdr.undp.org/content/human-development-report-2021-22

UNEP (2019). *Emissions Gap Report 2019*. UNEP, Nairobi. https://www.unep.org/resources/emissions-gap-report-2019

UNEP/MAP, and Plan Bleu (2020). *State of the Environment and Development in the Mediterranean*. Nairobi. https://planbleu.org/wp-content/uploads/2021/04/SoED_full-report.pdf

UNESCO-IOC (2021). *The United Nations Decade of Ocean Science for Sustainable Development (2021-2030): Implementation Plan*. UNESCO, Paris (ICO Ocean Decade Series, 20). https://unesdoc.unesco.org/ark:/48223/pf0000377082

UNFCCC (2015). *The Paris Agreement*. United Nations Framework Convention on Climate Change (UNFCCC). https://unfccc.int/documents/184656

Veland S., Howitt R., Dominey-Howes D., Thomalla F., and Houston D. (2013). Procedural vulnerability: Understanding environmental change in a remote indigenous community. *Global Environmental Change*, *23*(1), 314–326. doi: 10.1016/j.gloenvcha.2012.10.009

Wall G., and Badke C. (1994). Tourism and climate change: An international perspective. *Journal of Sustainable Tourism*, *2*(4), 193–203. doi: 10.1080/09669589409510696

WCED (1987). *Report of the World Commission on Environment and Development: 'Our common future' [Brundtland report].* Geneva, Switzerland: United Nations. http://www.un-documents.net/our-common-future.pdf

Williams O. D. (2020). COVID-19 and Private Health: Market and Governance Failure. *Development*, *63*(2–4), 181–190. doi: 10.1057/s41301-020-00273-x

Winkel R., Weddige U., Johnsen D., Hoen V., and Papaefthimiou S. (2016). Shore Side Electricity in Europe: Potential and environmental benefits. *Energy Policy*, *88*, 584–593. doi: 10.1016/j.enpol.2015.07.013

Information about the authors

Coordinating Lead Authors

Stefano MONCADA, Islands and Small States Institute, University of Malta, *Msida, Malta*
Salpie DJOUNDOURIAN, Adnan Kassar School of Business, Lebanese American University, *Byblos, Lebanon*
Suzan KHOLEIF, National Institute of Oceanography and Fisheries, *Cairo, Egypt*

Lead Authors

Margaret CAMILLERI-FENECH, Institute for Climate Change and Sustainable Development, University of Malta, *Msida, Malta*
Mita DRIUS, Faculty of Education, Free University of Bozen-Bolzano, *Bressanone, Italy*
Francesca SPAGNUOLO, Independent Researcher, *Italy*

Annex I: Acronyms, Abbreviations, Chemical symbols, and Scientific Units

Acronyms

3D	Three-Dimensional
ADHD	Attention Deficit Hyperactivity Disorder
AMD	Acid Mine Drainage
AQG	Air Quality Guideline
AR5	5th Assessment Report (of the IPCC)
AR6	6th Assessment Report (of the IPCC)
ARLEM	Euro-Mediterranean Regional and Local Assembly (French: Assemblée Régionale et Locale Euro-Méditerranéenne)
BAC	Background Assessement Concentration
BaP	Benzo [a]pyrene
BCC	Beach Carrying Capacity
BCE	Before the Common Era
CCP	Cross-Chapter Paper
CE	Common Era
CEB	Council of Europe Development Bank
CEDARE	Center for Environment and Development for the Arab Region and Europe
CENALT	National Tsunami Warning Center (French: CENtre d'Alerte aux Tsunamis)
CIESM	Mediterranean Science Commission (French: Commission Internationale pour l'Exploration Scientifique de la Méditerranée)
CLIA	Cruise Lines International Association
CMIP	Coupled Model Intercomparison Project
COP	Conference of the Parties
COPD	Chronic Obstructive Pulmonary Disease
CRD	Climate Resilient Development
CWs	Constructed Wetlands
DAS	Distributed Acoustic Sensing
DDT	Dichlorodiphenyltrichloroethane
DEMs	Digital Elevation Models
DRR	Disaster Risk Reduction
e.g.	exempli gratia or 'for example'
EAC	Environmental Assessment Criteria
EC	European Commission
ECA	Emission Control Area
EDCs	Endocrine-Disrupting Chemicals
EEA	European Environment Agency
EGCSs	Exhaust Gas Cleaning Systems
EGMS	European Ground Motion Service
EIB	European Investment Bank
EIU	Economic Intelligence Unit
EMB	European Marine Board
EMSA	European Maritime Safety Agency
EMN	European Migration Network
EMS	Environmental Management Systems
EPs	Emerging Pollutants
ES	Ecosystem Services
ESG	Environmental, Social and Governance
et al.	et alii, or 'and others'
ETS	Emissions Trading System
EU	European Union
EU COST	European Cooperation in Science and Technology Action
ESCWA	United Nations Economic and Social Commission for West Asia
EUMS	European Union Member States
EWEA	European Wind Energy Association
EWS	Early Warning Systems
FAO	Food and Agriculture Organization
FOD	First Order Draft
GAM	Generalized Additive Model
GDP	Gross Domestic Product
GES	Good Environmental Status
GHG	Greenhouse gas(es)
GIA	Glacial Isostatic Adjustment
GII	Gender Inequality Index
GITEC	Genesis and Impact of Tsunamis on the European Coasts
GNI	Gross National Income
GNP	Gross National Product
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
HABs	Harmful Algal Blooms
HW	Heat Waves
i.e.	id est, or 'that is' and means 'in other words'
ICG/NEAMTWS	Intergovernmental Coordination Group for the Tsunami Early Warning and Mitigation System in the north-eastern Atlantic, the Mediterranean and Connected Seas
ICZM	Integrated Coastal Zone Management

IMAP	Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast
INGV	National Institute of Geophysics and Volcanology (Italian: Instituto nazionale di geofisica e vulcanologia)
InSAR	Interferometric Synthetic Aperture Radar
IOC-UNESCO	Intergovernmental Oceanographic Commission of UNESCO
IOM	International Organization for Migration
IP	Implementation Plan
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IPMA	Portuguese Institute for Sea and Atmosphere (Portuguese: Instituto Protuguês do Mar e da Atmosfera) (Portugal)
IQ	Intelligence Quotient
IRENA	International Renewable Energy Agency
ISDR	International Strategy for Disaster Risk Reduction
ISP	Idiopathic Spontaneous Pneumothorax
IUCN	International Union for Conservation of Nature
JJA	June July August
JPOI	Johannesburg Plan of Implementation
KOERI	Kandilli Observatory and Earthquake Research Institute (Türkiye)
LiDAR	Light Detection and Ranging
LECZ	Low Elevation Coastal Zone
LULUCF	Land Use, Land-Use Change and Forestry
MAR1	First Mediterranean Assessment Report (of the MedECC)
MMEs	Mass Mortality Events
MAP	Mediterranean Action Plan
MATTM	Ministero dell'Ambiente e della Tutela del Territorio e del Mare - former name (2006 – 2021) of the Italian Ministry of the Environment (Italy)
MDGs	Millennium Development Goals
MED POL	Programme for the Assessment and Control of Marine Pollution in the Mediterranean
MCSD	Mediterranean Commission on Sustainable Development
MedECC	Mediterranean Experts on Climate and environmental Change
MedPAN	Network of Marine Protected Areas managers in the Mediterranean
MENA	Middle East and North Africa
MMS	Moment Magnitude Scale (denoted explicitly with Mw or Mwg, and generally implied with use of a single M for magnitude)
MOSE	Experimental Electromechanical Module (Italian: Modulo Sperimentale Elettromeccanico)
MPA	Marine Protected Areas
MSFD	Marine Strategy Framework Directive
MSSD	Mediterranean Strategy for Sustainable Development
MHW	Marine Heat Wave
MSW	Municipal Solid Waste
MWO	Mediterranean Wetlands Observatory
NEAMTWS	North-Eastern Atlantic, Mediterranean, and Connected Seas Tsunami Warning Systems (France)
NGO	Non-Governmental Organisation
NMCs	Northern Mediterranean Countries
NOA	National Observatory of Athens (Greece)
NRDC	Natural Resources Defense Council
NTWS	National Tsunami Warning Systems
OCDE	Organisation for Economic Co-operation and Development
OCP	Ocean & Climate Platform
OCPs	Organochlorine Pesticides
OECMs	Other Effective Conservation Measures
OMEC	Organisation Méditerranéenne de l'Energie et du Climat (France) (formerly OME, Observatoire Méditerranéen de l'Energie)
OMW	Olive Mill Waste
OPFRs	Organophosphate Flame Retardants
PAHs	Polycyclic Aromatic Hydrocarbons
PAP/RAC	Priority Actions Programme / Regional Activity Center
PCBs	Polychlorinated Biphenyls
PCDD	Polychlorinated Dibenzodioxins
PCDF	Polychlorinated Dibenzofuran
PFASs	Perfluoroalkyl Substances
PFOS	Perfluorooctane sulfonates
PFCs	Perfluorinated Compounds
PM	Particulate Matter
POCs	Persistent Organic Chemicals
POPs	Persistent Organic Pollutants

PPCPs	Pharmaceutical and Personal Care Products
psu	practical salinity unit
PV	Photovoltaic
RAC	Regional Activity Centers
RCP	Representative Concentration Pathways
REMPEC	Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (Malta)
RH	Relative Humidity
RSLR	Relative Sea Level Rise
SBE	Sustainable Blue Economy
SDGs	Sustainable Development Goals
SEMC	Sectorial Emissions Reduction Strategies
SEMCs	Southern and Eastern Mediterranean Countries
SGD	Submarine Groundwater Discharge
SIDA	Swedish International Development Cooperation Agency
SLR	Sea Level Rise
SPAMI	Specially Protected Areas of Mediterranean Importance
SPI	Science Policy Interface
SPM	Summary for Policymakers
SRIA	Strategic Research and Innovation Agenda
SSE	Short-Side Electricity
SSP	Shared Socioeconomic Pathway
SoED	State of the Environment and Development in the Mediterranean
T&E	Transport and Environment
TCEs	Technology-Critical Elements
TSP	Tsunami Service Providers
TN	Tropical Night
UfM	Union for the Mediterranean
UHI	Urban Heat Island
UN	United Nations
UNDP	UN Development Programme
UNDRR	UN Office for Disaster Risk Reduction
UNEP	UN Environment Programme
UNESCO	UN Educational, Scientific and Cultural Organisation
UNEP/MAP	UN Environment Programme / Mediterranean Action Plan
UNFCCC	UN Framework Convention on Climate Change
UNTWO	UN World Tourism Organization
USD	United States dollar
USGS	United States Geological Survey
UV	Ultraviolet
UfM	Union for the Mediterranean
UfM CCEG	UfM Climate Change Expert Group
UfM WG ENV-CC	UfM Working Group on Environment and Climate Change
VOCs	Volatile Organic Compounds
WCRP	World Climate Research Programme
WGI	Working Group I of the IPCC
WGII	Working Group II of the IPCC
WGIII	Working Group III of the IPCC
WHO	World Health Organization
WHS	World Heritage Sites
WMO	World Meteorological Organization
ZOD	Zero Order Draft

Chemical Symbols

As	Arsenic
C	Carbon
Cd	Cadmium
CH_4	Methane
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
Cu	Copper
Cr	Chromium
Fe	Iron
Ga	Gallium
Ge	Germanium
H_2	Hydrogen gas
H_2O	Water
H_2O_2	Hydrogen Peroxide
H_2S	Hydrogen sulphide
Hg	Mercury
K	Potassium
La	Lanthanum
Mg	Magnesium
MeHg	Methylated Mercury
NaCl	Sodium Chloride
N	Nitrogen
N_2	Nitrogen gas
N_2O	Nitrous oxide
Na	Sodium
NaCl	Sodium Chloride
Ni	Nickel
NO_2	Nitrogen dioxide
NO_3^-	Nitrate ion
NO_x	Nitrogen oxides (NO_x refers to air pollutants from combustion processe)
O_3	Ozone
P	Phosphorus
Pb	Lead
PFC	Perfluorocarbon

Pt	Platinum	**Te**	Tellurium
SF_6	Sulfur hexafluoride	**Zn**	Zinc
Si	Silicon	**ZnO**	Zinc oxide
SO_2	Sulfur dioxide		
SO_x	Sulfur oxides		

Scientific Units

SI (Système International) units[87]

Physical quantity	*Name of unit*	*Symbol*
Amount of substance	mole	mol
Energy	joule	J
Length	metre	m
Mass	kilogram	kg
Time	second	s
Thermodynamic temperature	kelvin	K

SI-derived units with special names

Physical quantity	*Unit*	*Symbol*	*Definition*
Energy	joule	J	kg m^2 s^{-2}
Force	newton	N	kg m s^2
Power	watt	W	kg m^2 s^{-3} (= J s^{-1})
Pressure	pascal	Pa	kg m^{-1} s^{-2} (= N m^{-2})

SI Prefixes (Fraction and Multiples)

Fraction	*Prefix*	*Symbol*	*Multiple*	*Prefix*	*Symbol*
10^{-1}	deci	d	10	deca	da
10^{-2}	centi	c	10^2	hecto	h
10^{-3}	milli	m	10^3	kilo	k
10^{-6}	micro	µ	10^6	mega	M
10^{-9}	nano	n	10^9	giga	G
10^{-12}	pico	p	10^{12}	tera	T
10^{-15}	femto	f	10^{15}	peta	P
10^{-18}	atto	a	10^{18}	exa	E

Non-SI units, quantities and related abbreviations

Type	*Unit*	*Symbol*
Acidity (hydrogen ion activity)	pH (dimensionless)	pH
Area	hectare	ha (1 ha = 10,000 m^2)
CO_2 Emissions	metric tonne CO_2	tCO_2
CO_2 -equivalent Emissions	metric tonne CO_2-eq	tCO_2 eq
Concentration	parts per million (dimensionless)	ppm (=10^{-6})
Concentration	parts per billion (dimensionless)	ppb (= 10^{-9})
Currency	euro, dollar, US dollar	€, $, USD
Electricity/Heat generation	watt hour[88]	Wh(1 Wh = 3600 J)
Percent	percent (dimensionless, 1/100)	%
Temperature	degree Celsius[87]	°C (t/°C = T/K – 273.15
Time	year	yr

---

[87] Official SI Brochure for authoritative definitions: https://www.bipm.org/en/publications/si-brochure/

[88] Accepted for use with the SI

Annex II: Contributors to the MedECC Special Report Climate and Environmental Coastal risks in the Mediterranean

Report coordinators

Salpie DJOUNDOURIAN, Adnan Kassar School of Business, Lebanese American University, *Byblos, Lebanon*
Piero LIONELLO, Department of Biological and Environmental Sciences and Technologies (DiSTeBA), University of Salento, *Lecce, Italy*
María Carmen LLASAT, Department of Applied Physics, University of Barcelona, *Barcelona, Spain*

Chapter 1
Introduction and framing

Coordinating Lead Authors
Anna PIRANI, Euro-Mediterranean Centre on Climate Change (CMCC), *Venice, Italy*
Agustín SÁNCHEZ-ARCILLA, Laboratori d'Enginyeria Marítima, Universitat Politècnica de Catalunya · BarcelonaTech (UPC), *Barcelona, Spain*

Lead Authors
Ana IGLESIAS, Research Centre for the Management of Agricultural and Environmental Risks (CEIGRAM), Universidad Politécnica de Madrid (UPM), *Madrid, Spain*
Elham ALI, Suez University / The National Authority for Remote Sensing & Space Sciences (NARSS), *Cairo, Egypt*

Contributing Authors
Mounir GHRIBI, National Institute of Oceanography and Applied Geophysics (OGS), *Trieste, Italy*
Katarzyna MARINI, MedECC Secretariat / Plan Bleu, *Marseille, France*
Daria POVH ŠKUGOR, UN Environment Programme / Mediterranean Action Plan (UNEP/MAP), Priority Actions Programme Regional Activity Centre (PAP/RAC), *Split, Croatia*

Chapter 2
Drivers and their Interactions

Coordinating Lead Authors
Murat BELIVERMIS, Department of Biology, Faculty of Science, Istanbul University, *Istanbul, Türkiye*
Dario CAMUFFO, National Research Council of Italy (CNR), Institute of Atmospheric Sciences and Climate, *Padua, Italy*

Lead Authors
Nuno CAIOLA, Department of Climate Solutions and Ecosystem Services, Eurecat, *Amposta, Spain*
Claudio FERRARI, Department of Economics, University of Genoa, *Genoa, Italy*
Nadia MHAMMDI, Institut Scientifique, University Mohammed V of Rabat, *Rabat, Morocco*
Estela ROMERO, Global Ecology Unit, Centre for Ecological Research and Forestry Applications (CREAF), *Barcelona, Spain*
Claudia WOLFF, Institute of Geography, Kiel University, *Kiel, Germany*

Contributing Authors
Vincenzo ASERO, Department of Political and Social Sciences, University of Catania, *Catania, Italy*
Sana BEN ISMAIL, Institut National des Sciences et Technologies de la Mer, *Tunis, Tunisia*
Cem DALYAN, Department of Biology, Faculty of Science, Istanbul University, *Istanbul, Türkiye*

Hamouda DAKHLAOUI, University of Tunis El Manar, National Engineering School of Tunis, Laboratory of Modelling in Hydraulics and Environment, Tunis, Tunisia / University of Carthage, National School of Architecture and Urban Planning of Tunis, *Sidi Bou Said, Tunisia*
Lena REIMANN, Instituut voor Milieuvraagstukken (IVM) – Institute for Environmental Studies, Faculty of Science, Vrije Universiteit Amsterdam (VU), *Amsterdam, The Netherlands*
Alessio TEI, Department of Economics | DIEC, University of Genoa, *Genoa, Italy*
Matteo VACCHI, Department of Earth Sciences, University of Pisa, *Pisa, Italy*
Antonio della VALLE, Institute of Atmospheric Sciences and Climate, National Research Council of Italy (CNR-ISAC), *Padua, Italy*

Chapter 3
Impacts and risks

Coordinating Lead Authors
Z. Selmin BURAK, Institute of Marine Sciences and Management, Istanbul University, *Istanbul, Türkiye*
Nathalie HILMI, Department of Environmental Economics, Centre Scientifique de Monaco, *Monaco*
José A. JIMÉNEZ, Laboratori d'Enginyeria Marítima, Universitat Politécnica de Catalunya·BarcelonaTech, *Barcelona, Spain*

Lead Authors
Elham ALI, Suez University / The National Authority for Remote Sensing & Space Sciences (NARSS), *Cairo, Egypt*
Mario V. BALZAN, Institute of Applied Sciences, Malta College of Arts, Science and Technology, *Paola, Malta*
Alessandra BONAZZA, National Research Council of Italy (CNR), Institute of Atmospheric Sciences and Climate, *Bologna, Italy*
Marie-Yasmine DECHRAOUI BOTTEIN, Université Côte d'Azur, CNRS, ECOSEAS, *Nice, France*
Nazli DEMIREL, Institute of Marine Sciences and Management, Istanbul University, *Istanbul, Türkiye*
Shekoofeh FARAHMAND, Department of Economics, University of Isfahan, *Isfahan, Iran*
Mauricio GONZÁLEZ, IHCantabria – Instituto de Hidráulica Ambiental de La Universidad de Cantabria, *Santander, Spain*
Sebastián MONTSERRAT, Department of Physics, University of the Balearic Islands (UIB), *Palma, Spain*
David PULIDO-VELAZQUEZ, Spanish Geological Survey (IGME-CSIC), *Granada, Spain*
Alain SAFA, Université Côte d'Azur, IAE, GRM, *Nice, France*
Matteo VACCHI, Department of Earth Sciences, University of Pisa, *Pisa, Italy*

Contributing Authors
Ignacio AGUIRRE AYERBE, IHCantabria – Instituto de Hidráulica Ambiental de La Universidad de Cantabria, *Santander, Spain*
Iñigo ANIEL-QUIROGA, IHCantabria – Instituto de Hidráulica Ambiental de La Universidad de Cantabria, *Santander, Spain*
Nuno CAIOLA, Department of Climate Solutions and Ecosystem Services, Eurecat, *Amposta, Spain*
Emma CALIKANZAROS, Université Côte d'Azur, CNRS, ECOSEAS, *Nice, France*
Dario CAMUFFO, National Research Council of Italy (CNR), Institute of Atmospheric Sciences and Climate, *Padua, Italy*
Mine CINAR, Department of Economics, Loyola University Chicago, *Chicago, USA*
María Carmen LLASAT, Department of Applied Physics, University of Barcelona, *Barcelona, Spain*
Alban THOMAS, Grenoble Applied Economics Laboratory (GAEL), University Grenoble-Alpes, INRAE, *Grenoble, France*

Chapter 4
Managing climatic and environmental risks

Coordinating Lead Authors
Mohamed ABDRABO, Alexandria Research Center for Adaptation to Climate Change (ARCA), Alexandria University, *Alexandria, Egypt*
Athanasios T. VAFEIDIS, Institute of Geography, Kiel University, *Kiel, Germany*

Lead Authors
Gonéri Le COZANNET, French Geological Survey (Bureau de Recherche Géologique et Minière, BRGM), *Orléans, France*
Savvas GENITSARIS, National and Kapodistrian University of Athens, *Athens, Greece*
Michelle PORTMAN, Faculty of Architecture and Town Planning, Technion – Israel Institute of Technology, *Haifa, Israel*
Daria POVH ŠKUGOR, UN Environment Programme / Mediterranean Action Plan (UNEP/MAP), Priority Actions Programme Regional Activity Centre (PAP/RAC), *Split, Croatia*

Contributing Authors
Cécile CAPDERREY, French Geological Survey (Bureau de Recherche Géologique et Minière, BRGM), *Orléans, France*
Sinja DITTMANN, Leibniz Institute for Science and Mathematics Education & Institute of Geography, Kiel University, *Kiel, Germany*
Joachim GARRABOU, Institut de Ciències del Mar (ICM-CSIC), Spanish National Research Council (CSIC), Spanish National Research Council (CSIC), *Barcelona, Spain*
Mauricio GONZÁLEZ, IHCantabria – Instituto de Hidráulica Ambiental de La Universidad de Cantabria, *Santander, Spain*
Sebastián MONTSERRAT, Department of Physics, University of the Balearic Islands (UIB), *Palma, Spain*
Marie PETTENATI, French Geological Survey (Bureau de Recherche Géologique et Minière, BRGM), *Orléans, France*
Agustín SÁNCHEZ-ARCILLA, Laboratori d'Enginyeria Marítima, Universitat Politècnica de Catalunya · BarcelonaTech (UPC), *Barcelona, Spain*

Chapter 5

Sustainable development pathways

Coordinating Lead Authors
Stefano MONCADA, Islands and Small States Institute, University of Malta, *Msida, Malta*
Salpie DJOUNDOURIAN, Adnan Kassar School of Business, Lebanese American University, *Byblos, Lebanon*
Suzan KHOLEIF, National Institute of Oceanography and Fisheries, *Cairo, Egypt*

Lead Authors
Margaret CAMILLERI-FENECH, Institute for Climate Change and Sustainable Development, University of Malta, *Msida, Malta*
Mita DRIUS, Faculty of Education, Free University of Bozen-Bolzano, *Bressanone, Italy*
Francesca SPAGNUOLO, Independent Researcher, *Italy*

Editors

Report Coordinators
Salpie DJOUNDOURIAN, Adnan Kassar School of Business, Lebanese American University, *Byblos, Lebanon*
Piero LIONELLO, Department of Biological and Environmental Sciences and Technologies (DiSTeBA), University of Salento, *Lecce, Italy*
María Carmen LLASAT, Department of Applied Physics, University of Barcelona, *Barcelona, Spain*

MedECC Coordinators
Joël GUIOT, CNRS, CEREGE, *Aix-en-Provence, France*
Fatima DRIOUECH, University Mohammed VI Polytechnic, *Rabat, Morocco*
Wolfgang CRAMER, CNRS, IMBE, *Aix-en-Provence, France*

MedECC Secretariat
Julie Claire GATTACCECA, MedECC Secretariat/AIR Climat, *Marseille, France*
Katarzyna MARINI, MedECC Secretariat/Plan Bleu, *Marseille, France*

Annex III: List of expert reviewers

ASCAME
Association of the Mediterranean Chambers of Commerce and Industry
Spain

ASLAN, Zafer
Istanbul Aydın University
Türkiye

BELLIERES, Samson
Plan Bleu/Regional Activity Centre of the Mediterranean Action Plan (UN Environment/MAP)
France

CANALS, Miquel
University of Barcelona
Spain

CANALS-MOLINA, Josep
MedCITIES
Spain

CAVALERI, Luigi
Institute of Marine Sciences of the National Research Council of Italy (CNR-ISMAR)
Italy

CHOUCHANI CHERFAN, Carol
United Nations Economic and Social Commission for West Asia (ESCWA)
Lebanon

COUTAZ, Jonathan
Société SETEC HYDRATEC
France

CROVELLA, Tiziana
University of Bari Aldo Moro
Italy

DE CHEVEIGNÉ, Suzanne
Centre national de la recherche scientifique (CNRS), Centre Norbert Elias
France

EL M'RINI, Abdelmounim
Abdelmalek Essaâdi University (UAE)
Morocco

ELAOUD, Anis
Higher Institute of Environmental Sciences and Technologies - Carthage University
Tunisia

ENVIRONMENT GENERAL AUTHORITY
Libya

ENVIRONMENT AND RESOURCES AUTHORITY
ERA
Malta

EU
Delegation of the European Union to the Hashemite Kingdom of Jordan
Jordan

EU
Delegation of the European Union to the State of Israel
Israel

EUROPEAN ENVIRONMENT AGENCY (EEA)
Denmark

FERRÉ GARCIA, Tània
ESADE Center for Public Governance (EsadeGov)
Spain

FEDERAL FOREIGN OFFICE
Division 407 – Climate partnerships, bilateral climate cooperation
Germany

GALGANI, François
Institut français de recherche pour l'exploitation de la mer (IFREMER) French national institute for ocean science and technology
France

GERONIKOLOU, Styliani A.
Academy of Athens
Greece

IUCN – International Union for Conservation of Nature Centre for Mediterranean Cooperation
Spain

IVČEVIĆ, Ante
Vrije Universiteit Brussel (VUB)
Belgium & Aix-Marseille Université (amU)
France

JABEUR, Chedia
University of Monastir · High Institute of Biotechnology of Monastir
Tunisia

LAGHZAL, Ali
Higher Institute of Maritime Fisheries (ISPM)
Morocco

LASCURAIN, Josep
SGM
Spain

MARCOS, Marta
University of the Balearic Islands (UIB) / Mediterranean Institute for Advanced Studies (IMEDEA)
Spain

MARROUCH, Walid
Lebanese American University
Lebanon

MAUGIS, Pascal
Laboratoire des Sciences du Climat et de l'Environnement (LCSE)
France

MedPAN
Network of managers of marine protected areas in the Mediterranean
France

MERHEB, Mohammad
Institut Agro Rennes-Angers
France

MINISTRY OF ENVIRONMENT
Directorate General of Environment
Lebanon

MINISTRY FOR ENVIRONMENT, ENERGY AND ENTERPRISE
Malta

MINISTRY OF AGRICULTURE, RURAL DEVELOPMENT AND ENVIRONMENT
Cyprus

MINISTRY OF ENVIRONMENT
Egypt

MINISTRY FOR ECOLOGICAL TRANSITION AND DEMOGRAPHIC CHALLENGE
Spain

MINISTRY OF THE ENVIRONMENT, CLIMATE AND ENERGY
Slovenia

MINISTRY OF ENVIRONMENT, URBANISATION AND CLIMATE CHANGE
Türkiye

MILI, Sami
Higher Institute of Fisheries and Aquaculture
Tunisia

MONEM, Mohamed Abdel
Food and Agriculture Organisation of the United Nations (FAO) · Regional Office for the Near East and North Africa (RNE)
Egypt

PAIANO, Annarita
University of Bari Aldo Moro
Italy

PAQUIER, Anne-Eleonore
French Geological Survey (BRGM)
France

PROHOM, Marc
Meteorological Service of Catalonia
Spain

REALE, Marco
National Institute of Oceanography and Applied Geophysics (OGS)
Italy

RIFI, Mouna
National Agronomic Institute of Tunisia
Tunisia

OBSERVATOIRE NATIONAL DE L'ENVIRONNEMENT ET DU DÉVELOPPEMENT DURABLE (ONEM)
Direction de l'Observation, des Études et de la Planification
Morocco

OCEANCARE
Switzerland

OCEAN & CLIMATE PLATFORM
France

SAAD-HUSSEIN, Amal
Environment & Climate Change Research Institute, National Research Centre
Egypt

SAMARAS, Achilleas
Democritus University of Thrace
Greece

SENATORE, Alfonso
University of Calabria
Italy

UNION FOR THE MEDITERRANEAN
Water, Environment and Blue Economy Division
Spain

VERNIEST, Fabien
Tour du Valat – Research institute for the conservation of Mediterranean wetlands / Muséum National d'Histoire Naturelle (MNHN) *France*

VOUDOURIS, Konstantinos S.
Aristotle University of Thessaloniki (AUTH)
Greece

ZEITOUN, Mohammad Abdulkareem
Yarmouk University
Jordan

ZEREFOS, Christos
Academy of Athens
Greece

ZLATKOVIĆ, Slobodan
Agency for ecological consulting "Akvatorija"
Serbia

ISBN: 978-2-493662-02-6
www.medecc.org
Enquiries: contact@medecc.org

MedECC
Mediterranean Experts on Climate
and environmental Change