The Eastern Mediterranean Marine Environment Under Climate Pressure: Risks, Impacts, and Priorities for Action

Recommendations of an International High-Level Expert Group

Editors: Costas N. Papanicolas, Aristomenis Karageorgis, Michael Norton

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THE EASTERN MEDITERRANEAN MARINE ENVIRONMENT UNDER CLIMATE PRESSURE: RISKS, IMPACTS AND PRIORITIES FOR ACTION - RECOMMENDATIONS OF AN INTERNATIONAL HIGH-LEVEL EXPERT GROUP

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Recommendations of an International High-Level Expert Group

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EDITORS

Prof. Costas N. Papanicolas, The Cyprus Academy of Sciences, Letters and Arts, Cyprus

Dr. Aristomenis Karageorgis, Hellenic Centre for Marine Research (HCMR), Greece

Prof. Michael Norton[1], European Academies Science Advisory Council (EASAC), Austria

AUTHORS (IN ALPHABETICAL ORDER)

Dr. Capt. Kazem S. M. Agamy, Director of the Maritime Graduates Affairs Center at the Arab Academy for Science, Technology and Maritime Transport, Egypt

Dr. Marina Argyrou, Director, Department of Fisheries & Marine Research, Cyprus

Prof. Michel Bariche, American University of Beirut, Lebanon

Prof. Zvi Ben-Avraham, Tel Aviv University; Israel Academy of Sciences and Humanities, Israel

Dr. Emmanouil Flaounas, Hellenic Centre for Marine Research (HCMR), Greece

Dr. Tilen Genov, Morigenos – Slovenian Marine Mammal Society, Slovenia

Dr. Abed El Rahman Hassoun, GEOMAR (Germany); CNRS-L (Lebanon)

Prof. Gerhard J. Herndl, University of Vienna, Austria

Dr. Paraskevi K. Karachle, Hellenic Centre for Marine Research (HCMR), Greece

Dr. Aristomenis Karageorgis, Hellenic Centre for Marine Research (HCMR), Greece

Prof. Ioannis Karakassis, University of Crete, Greece

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[1] Prof. Norton's contribution was supported by the European Academies Science Advisory Council (EASAC).

Prof. Petar Kružić, Faculty of Science, University of Zagreb, Croatia

Prof. Nikos Mihalopoulos, NOA, CLIMPACT, Greece

Dr. Dinos Mylonas, Hellenic Centre for Marine Research (HCMR), Greece

Dr. Marco Neira, Climate and Atmosphere Research Center (CARE-C), The Cyprus Institute, Cyprus

Prof. Michael Norton, European Academies Science Advisory Council (EASAC), Austria

Prof. Costas N. Papanicolas, The Cyprus Academy of Sciences, Letters and Arts, Cyprus

Dr. Constantine S. Parinos, Hellenic Centre for Marine Research (HCMR), Greece

Prof. Nadia Pinardi, University of Bologna, Italy; UN Ocean Decade DCC-CR

Prof. Serafeim E. Poulos, National and Kapodistrian University of Athens, Greece

Prof. Barış Salihoglu, METU Institute of Marine Sciences & Climate Center, Türkiye

Dr. Benedetto Sicuro, University of Turin, Italy

Prof. Dan Tchernov, Israel Academy of Sciences and Humanities / University of Haifa, Israel

Prof. Elina Tragou, University of the Aegean, Greece

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A **Coordination Committee** provided guidance and oversight to the project and comprised:

• **Prof. Costas N. Papanicolas**, Cyprus Academy of Sciences, Letters and Arts
• **Dr. Jackie Kado**, Network of African Science Academies (NASAC)
• **Prof. Brian Norton**, Vice President, European Academies' Science Advisory Council (EASAC)

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EXECUTIVE SUMMARY

The Eastern Mediterranean is widely recognised as one of the world's climate-change hotspots and is warming significantly faster than the global average. Its marine environment—one of the region’s most valuable shared resources—is increasingly exposed to interacting pressures from rising temperatures, marine heatwaves, sea-level rise, ocean acidification, altered circulation patterns, declining oxygen concentrations, invasive species, and growing anthropogenic pressures. These changes threaten biodiversity, ecosystem functioning, fisheries, aquaculture, coastal infrastructure, tourism, cultural heritage, and broader socio-economic resilience across the region.

This report builds upon previous work undertaken through the Eastern Mediterranean and Middle East Climate Change Initiative (EMME-CCI), including the Marine Environment and Resources Task Force, and reflects the work of an International High-Level Expert Group assembled under the auspices of the Cyprus Academy of Sciences, Letters and Arts in collaboration with EASAC and NASAC. It synthesizes current scientific understanding and identifies priorities for adaptation and policy action relevant to the Eastern Mediterranean.

The evidence reviewed indicates that observed changes in the Eastern Mediterranean are accelerating and, in several respects, appear to be evolving at rates closer to higher-emission scenarios than previously anticipated. The region is warming at nearly twice the global average, while marine heatwaves have increased markedly in frequency, duration, and intensity. Recent observations suggest that several indicators already approach or exceed lower-bound projections previously associated with later periods of the century.

Sea-level rise poses major medium to long-term risks to coastal populations, infrastructure, agriculture, tourism, and cultural heritage. While global mean sea-level rise remains the dominant driver, local effects—including land subsidence, sediment depletion, and storm surges—can substantially amplify impacts. Current evidence suggests that planning assumptions based on approximately one metre of sea-level rise by 2100 may provide a more prudent basis for adaptation planning than lower estimates commonly used in earlier assessments.

Ocean acidification is progressing throughout the Mediterranean and may interact synergistically with warming and deoxygenation. Although many impacts remain uncertain and species-specific, evidence suggests increasing risks for calcifying organisms and the potential for broader ecosystem shifts. These effects

may favour some organisms while disadvantaging others, contributing to altered ecological balances and long-term restructuring of marine ecosystems.

The Eastern Mediterranean is also particularly vulnerable to biological invasions. More than one thousand non-indigenous species have entered the Mediterranean, with over five hundred arriving through the Suez Canal. Rising temperatures increasingly favour tropical and thermophilic species and may accelerate the displacement of native species and habitats. The interactions among warming, invasive species, and ecosystem degradation are likely to constitute one of the dominant drivers of biodiversity change in the region.

Marine ecosystems and their services are already undergoing significant transformation. Changes in species distributions, degradation of habitats, increases in harmful algal blooms, recurrent mass mortality events, and potential shifts toward jellyfish-dominated ecosystems have implications for biodiversity and for economically important sectors including fisheries and aquaculture. Marine heatwaves are emerging as one of the most immediate and severe stressors.

Aquaculture, a rapidly growing sector of strategic importance in the Eastern Mediterranean, faces increasing risks from warming, disease outbreaks, harmful algal blooms, marine heatwaves, and extreme events. While some opportunities for adaptation and innovation exist, maintaining resilience will require substantial investments in research, technology development, monitoring systems, and adaptive management practices.

The assessment identified significant gaps in scientific understanding and observational capacity. Many parts of the Eastern Mediterranean, particularly along southern coastlines, remain under-observed. Long-term coordinated monitoring programmes are often fragmented or insufficiently resourced, limiting the capacity to detect emerging trends, evaluate impacts, and guide effective adaptation strategies.

Based on the evidence reviewed, several priorities emerge:

Immediate priorities

- Strengthening marine observation and monitoring systems.
- Enhancing modelling capabilities
- Expanding early-warning systems for marine heatwaves and extreme events.
- Enhancing surveillance and management of invasive species.

- Supporting targeted research on vulnerable ecosystems and species.

Medium-term priorities

- Incorporating adaptive planning approaches for sea-level rise and coastal infrastructure.
- Strengthening and expanding Marine Protected Areas and improving their management.
- Developing adaptation pathways for fisheries and aquaculture.
- Improving coordination and harmonization of monitoring protocols across countries.

Long-term priorities

- Strengthening regional scientific infrastructure and collaborative research networks.
- Expanding transboundary cooperation mechanisms.
- Supporting integrated approaches linking climate adaptation, biodiversity protection, and sustainable development.

The Eastern Mediterranean marine environment constitutes a shared and interconnected system whose challenges transcend national boundaries. Addressing the growing pressures of climate change requires sustained investment in scientific research, long-term observations, and the strengthening of regional knowledge infrastructures capable of identifying emerging risks and informing adaptive responses. Learned societies and scientific academies have an important role to play in synthesizing knowledge, fostering scientific dialogue, and providing independent science-based advice to decision makers. Effective responses will also require strengthened cooperation among transnational, regional, and national authorities, working in partnership with research institutions and civil society. Such collaboration can help bridge scientific understanding and policy implementation and support coordinated actions capable of enhancing resilience across the region.

1. BACKGROUND

In March 2019, the President of Cyprus initiated the Eastern Mediterranean and Middle East Climate Change Initiative (EMME-CCI) to address the threats posed to the eighteen countries comprising the EMME region. Its 450 million inhabitants are at risk of a 5 °C increase in mean annual temperature by the end of the century under a "business as usual" scenario, threatening catastrophic damage to the environment and society to the point of social collapse and mass migration- unless immediate action is taken on mitigation and adaptation through strong regional cooperation.

This initiative led to a Regional Action Plan that was adopted in November 2022 by the heads of EMME states in Sharm el-Sheikh at COP27. The Plan launched thirteen thematic Task Forces comprised of over 240 scientists under the coordination of The Cyprus Institute. As part of this initiative, a task force on the Marine Environment and Resources was set up and published its report in November 2025 (Karageorgis *et al.*, 2025). This major work has over 50 authors and hundreds of references, and is an immensely valuable compendium of scientific knowledge covering the geographical setting, physical and biochemical functioning, sea level changes, ocean carbon cycle and ocean acidification, ecological impacts, invasive species, impacts on marine fisheries, impacts on aquaculture and other aspects.

The Eastern Mediterranean part[2] of this study complements the extensive work in the Western Mediterranean and the Mediterranean as a whole by other initiatives including the Mediterranean Experts on Climate and Environmental Change (MedECC) and Plan Bleu, and interacts with regional bodies such as the Barcelona Convention and UNEP's Mediterranean Action Plan, the FAO's General Fisheries Commission for the Mediterranean (GFCM) and the Union for the Mediterranean. Most recently, the European Commission has launched its Mediterranean Pact initiative (EC 2025) to deepen cooperation with Southern Mediterranean countries (Algeria, Egypt, Israel, Jordan, Lebanon, Libya, Morocco, Palestine, Syria, and Tunisia). These initiatives straddle economic development, climate action, security, human connections, the conservation and the sustainable use of living marine resources and aquaculture, with an emphasis on integration throughout the Mediterranean and increasing both North–South and South-South integration.

Scientific inputs to the policy process are provided through regional consortia of national science academies- through EASAC (European Academies Science Advisory Council), NASAC (Network of African Science Academies) and AASSA (The Association of Academies and Societies of Science in Asia). The Global

[2] This report regards the Eastern Mediterranean as the sea over the Eastern Mediterranean Basin (east of the Strait of Sicily) which includes, under the EU Marine Spatial Planning Directive, the Adriatic Sea, the Ionian Sea, the Aegean Sea and the Levantine Sea (see Poulos and Kotinas, 2021).

Inter-Academy Patnership (IAP) which encourages collaboration between these regional groups supported an initiative by EASAC and the Cyprus Academy to engage experts from national academies to update the EMME-CCI work and identify key policy implications of the enhanced scientific understanding on the Eastern Mediterranean and its marine ecosystem and resources.

This project, led by the Cyprus Academy and the Cyprus Institute, assembled an expert group (Annex 1) which met in Cyprus during November 21- 22, 2025, to address key issues from a policy perspective. Assessing the impacts on the marine environment requires examining a complex system illustrated in Figure 1.1, and accordingly 6 sessions were held to address the following aspects:

- Physical processes affecting the marine ecosystem (sea–atmosphere interactions, extreme events, hypoxia)
- Sea-level rise
- Ocean acidification
- Impacts on marine ecosystems (biodiversity, habitats, fisheries, cumulative stressors)
- Non-indigenous and invasive species
- Aquaculture

A draft report was reviewed in a second workshop (on-line) on February 3, 2026, and the resulting report is presented here. It first identifies key policy priorities, which are summarised in Section 2 while the science supporting the expert group's conclusions is presented in subsequent Sections.

This study fully recognises that the warming taking place in the Eastern Mediterranean is the result of global emissions of greenhouse gases, to which bordering countries account for just 3-4% of the global total, even though the region is developing its own climate change policies and mitigation strategies (including encouraging 'Blue Carbon' measures (EMB, 2023)), these have limited influence on overriding global trends, so this report examines the regional and local impacts, and explores local policy options that can mitigate or adapt to changes driven by global emissions. By fully understanding the processes driving ecosystem changes in the marine environment, adverse impacts may be reduced, as summarised in the next section where the main adverse impacts, possible countermeasures and the organisations that can choose to apply the related policies, are tabulated.

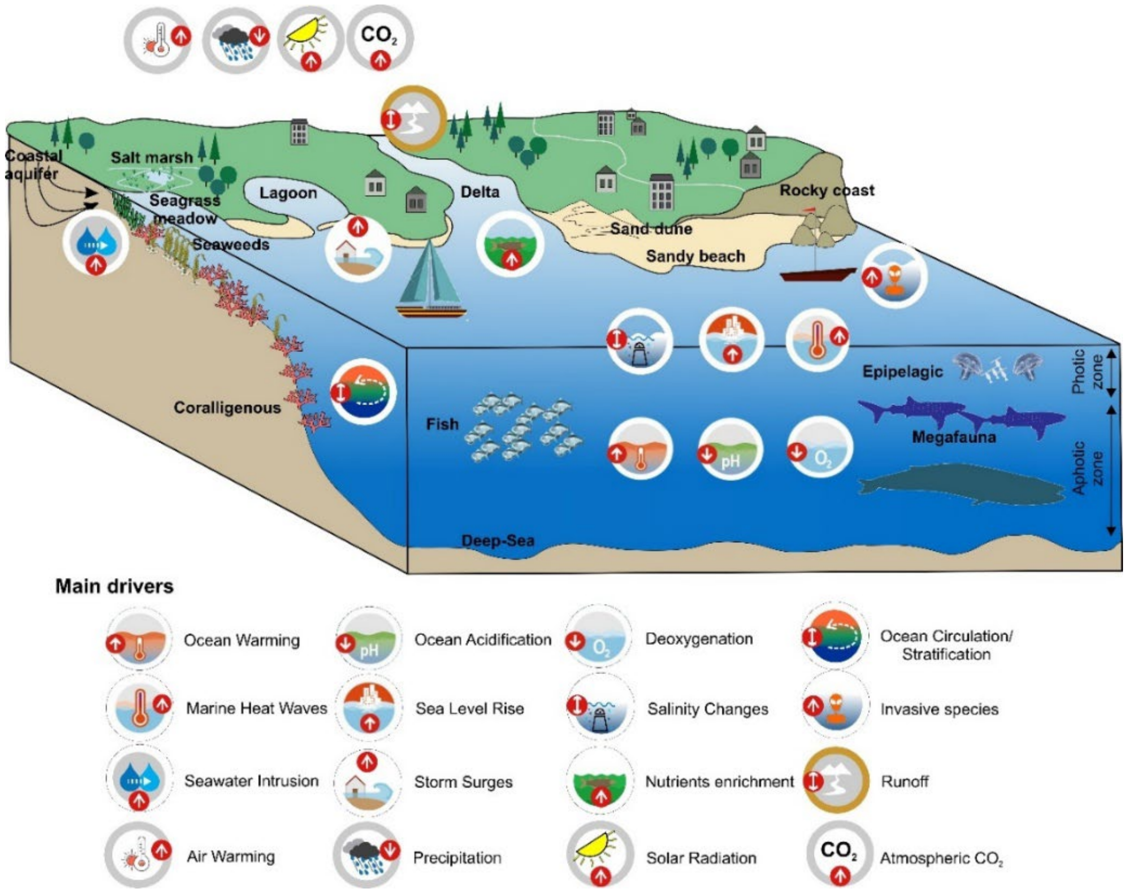

Figure 1.1. **Schematic illustration of the multiple drivers and processes in the Mediterranean marine ecosystem**. Source: Reproduced from Hassoun *et al.* (2025), Scientific Reports, under Creative Commons CC BY 4.0.

2. SUMMARY OF MEASURES TO MINIMISE NEGATIVE EFFECTS OF CLIMATE CHANGE IN THE EASTERN MEDITERRANEAN

[Timescale: Immediate (now onwards); Medium (up to 2050); Long: (2050 to 2100)]

Adverse Effect	Urgency/ timescale	Impact(s)	Countermeasures	Actors
A) Physical and meteorological processes				
Sea Level Rise	Immediate	Irreparable damage to cultural heritage monuments	Plan for up to 1 m rise by 2100. (2000 baseline)	National Governments UNESCO
	Medium -Long	Inundation of coastal infrastructure (e.g. ports)	Adjust facilities to cope with a SLR of up to 1m by 2100	Local authorities Port authorities
	Medium-Long	Beach losses	Sand nourishment (or seasonal removal/storage), nature-based solutions such as reefs or underwater structures	Local beach owners Local Authorities
Reduced rainfall in conjunction with sea level rise	Immediate	Salt intrusion pushes back the freshwater table 40-fold. Increase of salinity, changes of regional ocean circulation	Coastal aquifer management Enhance monitoring	Local water suppliers Regional authorities Marine observation resources
Low sediment inputs from river by damming	Immediate	Beach losses	Change the structure of dams to allow for sediment delivery downstream	Regional and national authorities
Warming and Marine Heatwaves	Immediate	Mass die-offs, damage to aquaculture	Plan for higher levels of warming than IPCC 4.5 scenario, and plan to adapt to	Governments to consider increased risk in infrastructure and

Adverse Effect	Urgency/ timescale	Impact(s)	Countermeasures	Actors
			increased frequency and intensity of MHW -Improvement of early-warning systems -Improve ocean observations to reduce uncertainties in future projections and improve preparedness of EMED nations	emergency response planning Marine observation resources
Increase of storm surge extremes	Immediate	Beach losses	'Grey' (infrastructure) and 'green' (nature-based) solutions such as dunes, seagrass	Local and national authorities
Medicanes	Immediate	Immediate impacts: human losses and infrastructure damage due to windstorms and floods triggered by sea surges and heavy rain. Medium to long-term impacts on public health, pollution & deterioration of water bodies quality (coastal and marine)	Observation and Emergency Warning systems. Public awareness programmes	National and local government but also cross-border collaboration since medicanes usually affect more than one country
Weakening of regional circulation and of deepwater formation	Medium to Long	Stratification increases and hypoxia will lead to negative and irreversible effects on marine life	Monitoring and modelling to detect and predict weakening of overturning circulation, changes in water quality (DO), and ecosystem changes	Regional and International cooperation on optimizing ocean observations (e.g. MonGOOS, OA Med-Hub, GO2DAT/GO2NE), National and local authorities

Adverse Effect	Urgency/ timescale	Impact(s)	Countermeasures	Actors
B) Biological effects and ecosystem services				
Acidification	Medium to Long	In the mid-long term, may cause shifts in ecosystem functioning and impact several key biological groups (mainly calcifiers, e.g., corals, epipelagic ecosystems)	Monitoring of seawater CO_2 system trends (e.g., pH, total alkalinity, pCO_2) in EMED. Research on the elasticity and resistance of EMED species Strengthen supply of high-quality reference materials needed for measuring the seawater CO_2 system.	Regional and international cooperation in ocean observations and research. (OA Med-Hub/GOA-ON, BioECOOcean panel, MedECC), regional labs and funding entities
Desalination plants	Short to Medium	Destruction of coastal Ecosystems due to massive desalination discharges	Brine management, location of discharges. Research on impacts of existing desalination plants. Develop guidelines on best practice to reduce environmental impact. Use zero or low-brine emission technologies	Local water providers National Governments on guidelines and their application
Invasive Species (Non-indigenous species)	Immediate	Impacts on biodiversity and ecosystem functioning	a. Development of transnational early warning systems. b. Targeted removals (e.g. in MPAs). c. Enforcement of IMO ballast regulations. d. Development of ship hull cleaning technologies, protocols and regulations	IMO; State authorities; Other authorities (e.g. Port authorities, The Suez Canal authority) Innovative research on containment methods and valorisation of NIS

Adverse Effect	Urgency/ timescale	Impact(s)	Countermeasures	Actors
	Immediate	Impacts on ecosystem services (e.g. fisheries, tourism, infrastructure)	a. Develop new uses/markets. b. Raising awareness. c. Valorisation of key NIS	Innovation research FAO/GCFM; fishers organisations; fishmongers and food industry; general public
	Immediate	Impacts on human health	a. Raising awareness. b. Development of health protocols in high-risk areas for immediate action	Health authorities (including health practitioners; hospitals; first aid locations); general public
	Immediate	Restrict introduction of new invasive species	Prevention of new introductions (where feasible); including suggestions for mitigation measures in areas/pathways of entry	Port authorities (ballast, fouling organisms) Suez Canal Authority Regulation of the aquarium species trade
Aquaculture	Immediate onwards	Mortality, disease due to climate-related shocks	Comprehensive research with industry on resilience through management, species selection, genetic selection, avoidance of vulnerable sites such as shallow or enclosed waters etc.	EC Research Programs, research centres, universities and Industry actors
Shift to a jellyfish dominated ecosystem	Medium to Long	Loss of ecosystem services; especially fishing	Ecosystem monitoring and research on response options	Marine Research Organisations
Marine Protected Areas	Immediate	MPAs provide some protection for native species but also protect NIS species	Improved implementation of existing MPAs.	National Governments Regional coordination (UNEP/MedPAN)

Adverse Effect	Urgency/ timescale	Impact(s)	Countermeasures	Actors
			Extension to new areas (especially adjoining the southern coasts). Management to include preferential removal of NIS	EU assistance

<u>External factors interacting but not amenable to local control</u>

- Global emissions and the overall rate of warming globally
- Drying of the adjoining land mass exacerbating local warming
- Changes in freshwater hydrology- especially loss of freshwater input from rivers due to damming or over pumping
- Population movements
- Geo-engineering, for example solar radiation management at the global level may lead to even higher levels of carbon dioxide and acidification, although carbon dioxide removal technologies could have local application.

3. PHYSICAL PROCESSES AFFECTING THE MARINE ECOSYSTEM

The marine ecosystem is affected by its physical and chemical environment where key variables are sea temperature, salinity, dissolved oxygen, nutrients and other chemical effects such as acidity. Due to geographical and meteorological factors, the Western Mediterranean is characterized by lower salinity influenced by flows from the Atlantic, so the East is more isolated leading to higher salinity and warmer temperatures, while it is more affected by invasive species due to its proximity to their source through the Suez Canal (Section 7).

Temperature. The IPCC special report on the Mediterranean (IPCC, 2022) concluded that the sea surface has warmed by 0.29 °C–0.44 °C per decade since the early 1980s, with stronger trends in the eastern basin, while ocean acidity is also increasing. Temperature rises are observed across the whole water column (Kubin *et al*., 2023), and across the whole basin, with the Eastern Mediterranean more affected than the Western Mediterranean (Figure 3.1).

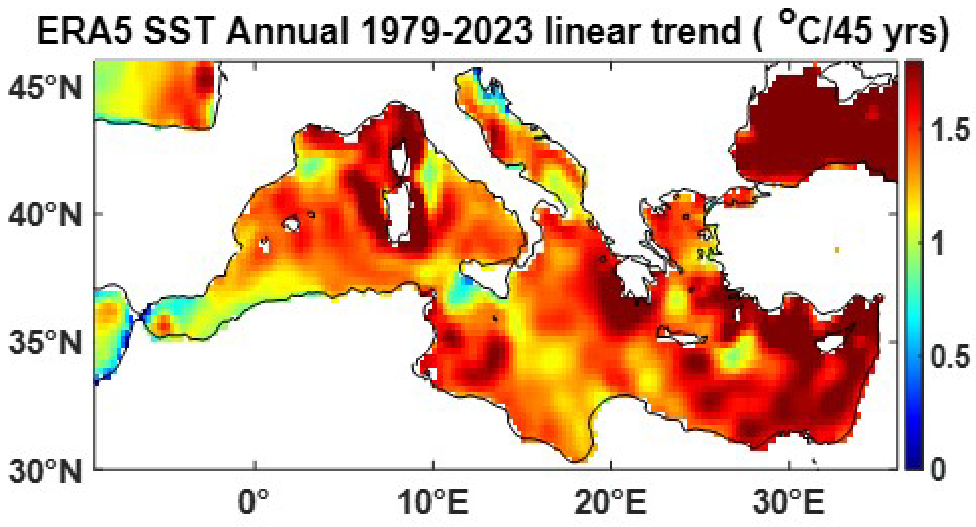

Figure 3.1. **Spatial pattern of linear trend (1979–2023) in annual mean SST (ºC / 45 years).** Source Skliris *et al*. (2025).

In 2024, the Mediterranean Sea recorded its highest annual sea surface temperature (SST), significantly exceeding the previous record set in 2023, with August 2024 setting a record high daily SST. Warming trends indicate an acceleration in warming (Figure 3.2) which has continued to 2025 with SST anomalies exceeding the previous highest in 2023.

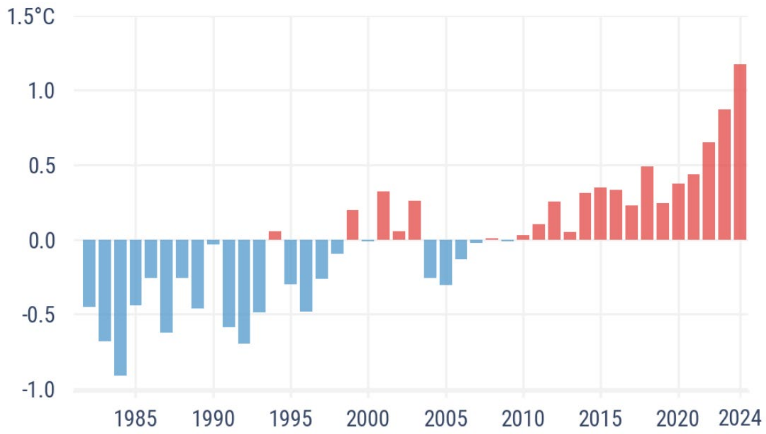

Figure 3.2. **Trends in SST anomalies across the Mediterranean**. Source: Fig 11.1 of ESOTC, 2024.

IPCC projected ocean warming in the range 0.8–3.8 °C by 2100 near the surface, 0.8–3.0 °C at intermediate depths, and 0.15–0.18 °C in deeper waters. The observed warming by 2025 of 1.3-1.4 °C is thus already well beyond the lower 2100 figure of 0.8 °C and close to the IPCC 'worst case' RCP 8.5 (business as usual) pathway. Indeed, the Eastern Mediterranean is warming almost twice the global average and Zittis *et al.* (2022) project an overall warming of >5 °C by 2100- well above the upper range of IPCC. At this level of warming, human survivability on land also becomes an issue.

Increasing temperatures lead to increased frequency and intensity of marine heatwaves[3] that have severe impacts on marine ecosystems and biodiversity, with socio-economic consequences on fisheries, aquaculture and tourism. Marine heatwaves have increased considerably in the past decade and, under RCP 8.5, IPCC project at least one long-lasting marine heat wave each year by 2100 that is up to 3 months longer and about four times more intense than present-day events.

A catalogue of the major Mediterranean MHWs that have occurred since 1982 was presented by Martinez *et al*. (2023); and the EMME report (Karageorgis *et al.*, 2025) pointed to increases in MHW events over the last two decades in both frequency (up 40%) and duration (15%). Pastor *et al.* (2025) show the increasing trend in Figure 3.3. The summers of 2022 and 2023 saw record-breaking MHWs, with some areas experiencing temperature anomalies up to 4.6°C above average, and it is projected (Wedler *et al.,* 2023) that MHWs in the Eastern Mediterranean

[3] The Copernicus Mediterranean Heat Waves Monitoring Service define a MHW as a prolonged discrete anomalously warm water event that should persist at least 5 days and exceed 90% of the historical temperature records at that location.

will occur seven times more often and last three times longer by the end of the 21st century.

Marine heatwaves and atmospheric heatwaves interact (Fortuny *et al*. 2025) and high SSTs in the Mediterranean have been linked to more intense storms and more extreme rainfall. For example, storm Daniel in 2023 (Argüeso *et al*., 2024), storm Boris in 2024, and the severe flooding in the Valencia region in 2024. Such 'medicanes' are responsible for diverse natural hazards, including torrential rainfall, flash floods, windstorms, and sea surges with profound socio-economic and ecological consequences (Khodayar *et al.*, 2026), particularly for coastal and densely populated areas. They not only comprise a hazard to infrastructure and loss of life but also medium to long term impacts on public health (Pasqualotto.*et al*., 2025; Rico *et al.*, 2026) and contamination of the coastal and marine environment (Lougkovois *et al.*, 2025). Over recent decades, trends in increasing temperature and salinity are accelerating (Skliris *et al.*, 2025) and since medicanes are driven by increasing SST, their intensity is expected to increase despite an overall reduction in precipitation (Chericoni *et al.*, 2025). It is not however possible to predict the occurrence or location of medicanes more than a few days in advance so preventative measures are limited to early warning systems and ensuring that potentially affected populations respond appropriately to warnings.

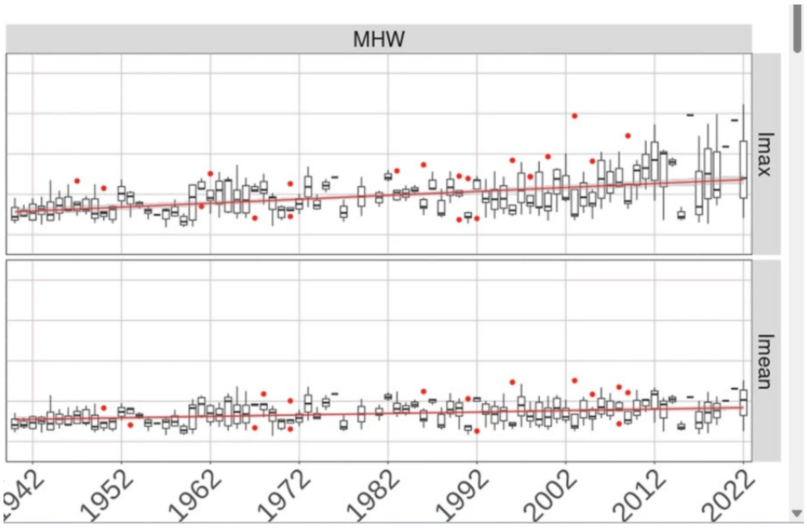

Figure 3.3. **Annual trends for marine heatwaves in the Mediterranean**. Source: Pastor *et al.* (2025). Imean: mean intensity; Imax: maximum intensity.

Salinity. the Mediterranean Sea typically averages around 38 parts per thousand (ppt) in surface waters (compared to 34-36 ppt in the Atlantic). Salinity tends to be higher in the Eastern Mediterranean, with values potentially reaching 40 ppt in the summer. Salt content is increasing particularly in deep waters (> 1000 m). The Eastern Mediterranean is notable for the presence of deep brine pools that are anoxic and support specialised microbial communities (Herut *et al.*, 2022).

Dissolved Oxygen. the EMME report noted that solubility reduces with higher water temperatures but that dynamical processes are dominant in determining dissolved oxygen interannual variability. Increasing temperatures combined with eutrophication are expected to increase impacts especially in coastal waters with nutrient inputs.

Regional climate models predict a slowing down of the Mediterranean overturning system that transports oxygen from surface to deeper waters (Soto-Navarro *et al.* 2020), and the most recent high-resolution simulations (Parras-Berrocal *et al.,* 2024) show a collapse of deep water formation in the Gulf of Lyon under the high emission scenario (RCP8.5) during mid-century, and a large reduction in the Eastern Mediterranean formation sites (projected dense water formation is reduced by 75 % for the Adriatic Sea, 84 % for the Aegean Sea, and 83 % for the Levantine Sea) by the end of the century. The resulting stratification will isolate the upper layers from the deep layers, leading to hypoxia that would have devastating impacts on pelagic and benthic marine ecosystems.

Overall, these underlying trends should inform risk analyses of extreme weather, marine ecosystem effects, MHWs, mass die-offs, and eutrophication/dead zones. The benchmark widely used for such risk assessments is the IPCC AR6 analysis, but recent evidence suggests that warming trends are closer to the IPCC worst case scenarios of business as usual (RCP8.5) and that extreme marine heatwaves are increasingly likely. Trends in hypoxia are less apparent, but several models suggest that temperature and salinity trends may weaken hitherto resilient deepwater formation in the Eastern Mediterranean, leading to stratification and reduced oxygen transfer to deeper waters, hypoxia and potentially catastrophic effects on the marine ecosystem.

4. SEA LEVEL RISE

Coastal areas and estuaries are at a growing risk of inundation and salinification as rising sea levels globally exacerbate extremes of high tides and storm surges locally. The Mediterranean has many historical and cultural sites that are vulnerable (e.g. Venice, Tyre, Delos and Alexandria), and these support tourism critical to local economies. Of the 49 UNESCO World Heritage sites on the Mediterranean rim, 47 are projected to be threatened by coastal flooding or erosion by 2100. Agriculture in the Nile Delta and elsewhere will also be adversely affected as well as coastal infrastructure. The social and economic impact of sea level rise is expected to be intense as summarised in Table 4.1.

The EMME report summarises trends in the Eastern Mediterranean as a result of the rise in global sea levels from thermal expansion of the oceans and increased inputs from ice melt. The IPCC AR6 projected sea level rise (SLR) of between 0.17 and 0.31 m for 2050, between 0.28 and 1.01 m for 2100 and between 0.37 and 1.88 m for 2150 relative to a 1994-2014 baseline. The rate of SLR locally is reported over the period 1993–2019 for the Levantine Sea as 2.6 ± 0.9 mm/yr, the Aegean Sea as 3.1 ± 1.0 mm/yr, and the Eastern Mediterranean as 3.23 ± 0.61 mm/yr, although trends for southern Crete appear insignificant (0.3 ± 1.3

mm/yr). Overall, the European Centre for Medium-Range Weather Forecasts notes that Mediterranean Sea level has been rising at an average pace of 2.8mm per year over the past 30 years and suggests that by 2100, sea level could have risen 90 cm above the year 2000 level, with local variations of up to 10 cm.

Table 4.1. **Social and Economic Impacts of Sea Level Rise (after Magnan *et al*., 2022).**

Type of damage	Examples
Direct loss of economic, ecological and cultural values	Loss of coastal landforms (beaches, wetlands), property, infrastructure. Reduction of ecosystem services (e.g. coastal tourism).
Marine Transport	Flooding or inundation of ports.
Coastal flooding (exacerbated by storms)	Coastal flooding impacts on agriculture, property. infrastructure and the population with loss of life.
Water supply	Salinization (or collapse) of coastal aquifers: e.g for the Gaza strip, a rise of 0.37 m in sea level increases sea water intrusion to the aquifer by 70 m (Qahman and Larab, 2006; Dimitriadis *et al.,* 2022).
Population pressures	Loss of land or livelihoods due to permanent inundation of coastal (usually deltaic) areas increases migration by those affected.

The dominant influence on Mediterranean SLR is of course the global mean, where future rises will depend on emission pathways and the associated increase in ocean temperatures and melting of glaciers and ice sheets. While the IPCC projects the range already mentioned, a wider range of 0.5–2 m for global SLR can be found in the literature. Recent studies suggest rates of loss from glaciers are accelerating even faster than those in the Greenland and Antarctic ice sheets (Hugonnet *et al*., 2021). This, together with studies on Greenland and Antarctica[4], led Grinsted and Christensen (2021) to suggest that IPCC models underestimate future sea level rise. A recent study by Hamlington *et al.* (2024) noted that the rate of global sea level rise doubled during the three decades from 1993 to 2023, suggesting that the sea level in 2100 will rise by an additional 169 mm relative to IPCC AR6 projections.

[4] Direct ice melting from warming can be increased by feedbacks such as where deep warmer water contact ice sheets leading to destabilization and grounding line retreat, leading to accelerations in ice loss (see e.g. DeConto *et al.,* 2021; Hill *et al*., 2024).

The above uncertainty in the average global SLR is superimposed on local variations caused by vertical land movements around the Mediterranean, for which Vecchio *et al*. (2024) find maximum and minimum differences of +1094 ± 103 mm and −773 ± 106 mm, to local SLR with an average value that exceeds IPCC projections by +80 mm along the northern coasts, adding to the inundation risk of 19,000 km of Mediterranean coasts. The European Knowledge Hub on Sea Level Rise (KH-SLR) has developed the 1st Assessment Report (Van den Hurk *et al.,* 2024) where projected mean SLR under the IPCC8.5 scenario is predicted to be 0.79 m (range 0.64–1.06 m) by 2100 relative to 1995–2014.

The risks from SLR may also be amplified by future extreme events from storm surges, waves and high tides, the frequency of which is expected to increase under all emission scenarios; indeed, the risk of seawater flooding that is currently only once every 100 years may become an annual phenomenon by 2100 in the IPCC high emission (RCP 8.5) pathway. This would exceed the rate at which sandy beaches can migrate (Monioudi *et al.*, 2017; Vousdoukas *et al.,* 2020); for instance, a SLR of 0.82 m leads to 21% of beaches along the Aegean totally eroded and 72% losing 50% or more (Monioudi *et al.,* 2018)**.** Lowering of sediment inputs from rivers as a result of upstream dams can also reduce sources of sediment that historically would have led to coastal beaches (Velegrakis A.F. *et al.*, 2008).

The economic impacts of sea level rise are likely to be significant in the medium term and an analysis of the economic damages due to climate-driven sea-level rise by Cortés Arbués *et al*. (2024) found that losses of GDP at the coast can be an order of magnitude larger than national losses, ranging from 9.56–20.84% of GDP. SLR can thus trigger sectoral rearrangement of both coastal and inland regional economies, and thus should be a priority concern for governments.

Coastal governments generally already have adaptation policies in place to respond to SLR but assumptions on the speed and scale of SLR may vary. The current evidence is that the speed and scale is likely to be greater than the IPCC figures on which many governments have based their policies, and a more prudent working assumption would be of the order of at least 1 metre by 2100 relative to a 2000 baseline.

However, uncertainty remains and thus planning to accommodate predicted future increases in SLR faces decision-makers with a trade-off between potentially investing too much too soon, or too little too late (e.g. Hall *et al.*, 2019). To address this, adaptive planning is favoured so that decisions are capable of adjustment as better estimates of SLR emerge. Adaptive decision-making is still at an early stage but some examples are available of how it may be applied at specific locations and deliver more cost-effective adaptation to sea level rise (e.g. Völz *et al.*, 2024). Responses that combine traditional, built infrastructure (grey) with natural, nature-based solutions (green) are likely to lead to more resilient, cost-effective, and multi-functional environmental and climate adaptation projects, especially for coastal protection, flood control, and water management. Such approaches can offer benefits like habitat creation and carbon storage alongside engineered safety.

Decisions at local level can be dominated by short-term issues, and medium- and long-term impacts of SLR and other climate change impacts ignored. Learning about sea level rise and the underlying uncertainties can thus improve coastal adaptation decisions and is the aim of the Copernicus Climate Change Service and the Union for the Mediterranean in providing climate data in an easy-to-use format[5].

The Nile delta is a particularly important resource and has been the focus of much study. The combined impact of SLR and local land subsidence are calculated to raise sea level by 1.0 m and inundate about 4500 square kilometres (19% of the delta area), affecting 6.1 million people. Studies have pointed to adaptation measures that include maintaining and building coastal protection structures, restoration of sand dunes along the shore, preserving existing wetlands, setting regulations to control development in vulnerable areas, change of land use, relocation of infrastructures into the landward side, and development of comprehensive monitoring and early warning systems (Eldeberky 2011), with related adaptation measures summarised in Abutaleb *et al*. (2018) and Sharaan *et al.* (2022).

5. ACIDIFICATION

The ocean absorbs between 20% and 30% of anthropogenic CO_2 emissions forming carbonic acid, which reduces the pH of seawater, a phenomenon known as ocean acidification (OA). As a result of increased CO_2 emissions, the average ocean pH globally has decreased from 8.2 to 8.1 since the industrial revolution, which is an increase of 30-40% in acidity (hydrogen ion concentration). Ocean pH is projected to decline by a further 0.3 to 0.4 pH units by 2100 depending on the emission scenario (Kwiatkowski *et al*., 2020). Increased acidity reduces the ability of some marine organisms such as corals, molluscs and some plankton to build and maintain their skeletons and shells. thereby inhibiting the growth of key species in the marine food chain.

The EMME Report describes the complex chemical interactions that convert carbon dioxide in the atmosphere to the carbonate and bicarbonate ions that are converted into calcium carbonate in shells and skeletons- mostly in the forms of calcite and aragonite. Due to local geomorphology and hydrology, the Eastern Mediterranean has a higher alkalinity than the open ocean with a pH of 8.09 to 8.11 and can absorb more CO_2, which can then be transported to deeper waters by active overturning circulation. This in turn means that the rate of acidification in the Eastern Mediterranean is faster than the global ocean; intermediate and deep waters also show a decline due to natural mixing processes. Yearly pH patterns show homogenous trends varying from -0.0021 to -0.0024 pH units y-1

[5] Jointly, they have created an application to assess the risks of coastal flooding and sea level rise on World Heritage Sites in the Mediterranean (https://climate.copernicus.eu/partnership-support-mitigation-and-adaptation-efforts-mediterranean#:~:text=In%20order%20to%20better%20understand%20the%20future, easy%2Dto%2Duse%20information%20to%20the%20cultural%20heritage%20sector.)

in the upper 80 m, while a high annual acidification rate was reported in shallow waters (< 5 m) of the South-Eastern coastal area (-0.009±0.004 pH unit y-1; Hassoun *et al.*, 2019; 2022), reflecting the capability of this sea to absorb larger amount of anthropogenic CO_2 that is then transferred to deep layers, compared to the global ocean (Schneider *et al.*, 2010; Hassoun *et al.*, 2015).

Acidity affects every organism in ways that are specific to its physiology and life cycle, so it is not possible to draw general conclusions on adverse effects of the incremental changes taking place. Globally, one global meta-analysis (Kroeker *et al.*, 2013) revealed decreased survival, calcification, growth, development and abundance in response to acidification across a broad range of marine organisms, while Alter *et al.* (2024) found that fish and invertebrates respond to warming and acidification in a wide range of deviations from the norm, leading to ecological shifts potentially impacting ecosystem structures and processes.

However, studies specific to the Mediterranean are few, and a review by Hassoun *et al.* (2022), found that individual species can be more or less sensitive. For example, the stony coral *Cladocora caespitosa* does not reduce its calcification rate with levels of acidification predicted to 2100, while Leung *et al.* (2022) found that echinoderms, crustaceans, and cephalopods were tolerant to near-future ocean acidification (down to a pH of ≈7.8 by 2100), while coccolithophores, calcifying algae, and corals appeared to be sensitive.

Hassoun *et al.* (2022) noted that multiple studies suggest that ocean warming and acidification can act synergistically to affect calcifying organisms. For example, warming can increase the metabolic demands of Mediterranean scleractinian corals, and when combined with lower pH, may impair cellular functions, potentially leading to mortality rates of up to 60%. Anthony *et al.* (2011) found that coral reef resilience to warming in the tropics was reduced by acidification, although the dominant cause of bleaching remains thermal shock. On the other hand, macroalgae- either as juveniles or adults- appear to benefit from elevated CO_2 with enhanced growth rates and tolerance to lowered pH (Gao *et al.*, 2019). Studies also show jellyfish to be resistant to acidification so that they can benefit from rising CO_2 and acidity levels (Hall-Spencer and Allen, 2015).

Outside the Mediterranean, a reduction has been found on the extent of calcification by foraminifera and adverse effects on corals that build up their structures from aragonite crystals (e.g. Mollica *et al.*, 2018). Sea snails that are an important food source both for fish and for whales have shells of aragonite that are also showing clear signs of dissolution (e.g. Bednaršek *et al.*, 2014).

Overall therefore, the scale and pace of acidification impacts is difficult to quantify and acidification also acts in synergy with the other two major stresses on the ecosystem of warming and invasive species. Since its effect is biased towards species depending on calcification in general and aragonite in particular, it may have a selective pressure against the most susceptible species and favour the growth of resistant species such as jellyfish, changing ecosystem structures.

The Eastern Mediterranean has limited data and more work is needed even on the basic chemical changes underway. Large areas are under-studied or not studied at all, such as its southern part adjoining North African countries. The "OA Med-Hub" (Ocean Acidification Mediterranean Hub) connects researchers studying how rising CO_2 affects the Mediterranean as part of a global network[6] but more monitoring efforts are needed to better understand the ongoing biogeochemical changes due to warming and ocean acidification, and their effects on species and possible future ecosystem shifts.

6. IMPACTS ON THE MARINE ECOSYSTEM

The marine environment and its biodiversity provide ecosystem services that may be threatened by rising temperatures, acidity and falling dissolved oxygen concentrations as shown in Figure 1.1 and in Table 6.1 below.

Table 6.1. **Potential Impacts of Climate Change on Marine Ecosystem Services**. Adapted from Help *et al.* (1998).

A) EFFECTS OF CLIMATE CHANGE

- Habitat alteration and loss: Rising sea levels threaten coastal erosion, nesting sites (e.g. for turtles), damaging coastal habitats. Warming and acidification degrade or destroy habitats such as coralligenous reefs and seagrass meadows.
- **Species decline and range shifts:** Warming and deoxygenation stress native species, causing population declines and northwards range shifts for cooler-water species.
- **Invasive species proliferation:** creates favourable conditions for the spread of non-indigenous species (NIS), which outcompete native organisms.
- **Increased extreme events:** More frequent and intense marine heatwaves can cause widespread mortality events.

B) IMPACTS ON ECOSYSTEM SERVICES

- Fisheries: Decline and shifts in distribution of native fish species, stress from warming and deoxygenation, threaten the sustainability of the fishing industry.
- Coastal protection: Damage to coastal habitats like wetlands and dunes reduces their ability to buffer against storm surges and erosion.
- Tourism and recreation: Damage to habitats and loss of iconic species affects the important tourism sector.
- Regulation: Changes in water temp., pH, and DO levels impact the ocean's ability to regulate nutrient cycling and carbon sequestration.

[6] The OA Mediterranean Hub includes scientists from fourteen countries: Algeria, Croatia, Cyprus, Egypt, France, Greece, Italy, Lebanon, Malta, Morocco, Slovenia, Spain, and Türkiye. https://www.goa-on.org/regional_hubs/mediterranean/about/introduction.php

The Mediterranean itself is a highly diverse marine ecosystem (it hosts 4-18% of the world's marine species despite being only 0.8% of the global ocean area), and the EMME Report reviews the extensive literature on effects of climate change and other stressors across the marine food chain- from phytoplankton through zooplankton to fisheries, and on benthic and pelagic species. Changes identified in the Eastern Mediterranean include:

- Primary productivity may increase in some areas although effects on marine plankton calcifiers are poorly understood.
- Degradation of benthic communities including macroalgal and sublittoral reef communities, decline of large corals.
- The frequency and intensity of eutrophication and occurrence of harmful algal blooms are expected to increase leading to hypoxia, toxicity, disease, and mass mortalities in reared fish populations.
- Marine fisheries are vulnerable due to warming as well as to overfishing and non-indigenous species. Models predict a marginal increase in total catch with "winner" species mostly pelagic thermophilic and/or exotic species of smaller size and low trophic level. Larger species of greater commercial interest are expected to decline. Southeastern countries (inc. Egypt and Tunisia) are the most vulnerable to climate change impacts.
- Further increases in acidification will drive ongoing reductions in marine biogenic calcification.
- Global warming is causing an expansion of the tropical jellyfish range triggering 'regime shifts' such as from fish to jellyfish. More than 500 new species have entered the region through the Suez Canal (see Section 7) including the common *Rhopilema nomadica,* and large blooms have become ubiquitous especially along the Israeli coasts.
- The spread of jellyfish is facilitated by overfishing of predator species; in turn, the increase in jellyfish removes food for juvenile fish as well consuming fish eggs and larvae. A Mediterranean Sea dominated by jellyfish is a possible future.

One phenomenon expected to continue to worsen is that of Marine Heatwaves (MHW) that cause mass mortality events. MHWs in 1999 and 2003 affected a multitude of sessile marine taxa and extended over thousands of kilometres of coastline. Five consecutive years of mass mortalities in the 2015-2019 period affected 50 marine taxa across 8 phyla. MHWs may also have contributed to a devastating epidemic in the fan mussel *Pinna nobilis* causing mortality rates higher than 90%, with only few and geographically limited refugia remaining. Among the species affected are Mediterranean corals, some of which have yet to recover from the 2003 mass mortality event (Gómez-Gras *et al.,* 2021). Smith *et al.* (2023) review the effect of MHW globally on broader ecosystem services and their socio-economic impacts on provisioning services such as fisheries and aquaculture, and provide a global baseline on which local impacts can be assessed.

Christou *et al*. (2025) discuss the impacts of ocean warming, marine heatwaves, ocean acidification and non-indigenous species in the Eastern Mediterranean and conclude that the primary factor causing biodiversity decline is the introduction of non-indigenous (invasive) species, exacerbated by warming. They recommend that further invasions via the Suez Canal should be prevented by discharging brine effluents from desalination plants along the Canal to create a salinity and temperature barrier.

Another recent study (Kostantchouk *et al.*, 2025) examined changes between 1989 and 2023 in the Eastern Mediterranean at depths ranging from 500 to 2500m. They found that the progressive increase in bottom water temperatures and primary production in the photic zone was associated with a major decrease in meiofaunal biomass and simplification of the benthic food webs, with adverse effects on the ecosystem services provided. Other recent studies follow the continued spread of jellyfish both in terms of new species and increased geographical extent of pre-existing species, and have shed further light on the complex interaction of biological, environmental, and anthropogenic factors influencing their spread (e.g. İşinibilir *et al.*, 2022; Fernandez-Alías *et al.*, 2023; Ramos-Perez *et al.*, 2025).

On fisheries, the Eastern Mediterranean is expected in climate models to see a small increase the fisheries biomass (Sailley *et al*., 2025) with hake and red mullet projected to increase. Tsagarakis *et al*. (2022) pointed to such scenarios of further warming offered the potential for higher yields of commercial species in the long term but only if short-term reductions in fishing effort are implemented. Countries however differ in the likely impact of changes expected with Egypt, Tunisia, and Libya the most vulnerable to changes anticipated in 17 commercial species and Slovenia, France, and Croatia the least vulnerable (Farahmand *et al*., 2023).

Marine ecosystem changes observed and expected to continue are mostly negative and reduce the ecosystem services that have hitherto been provided (Table 6.1). These adverse changes are the result of global warming with local amplification due to latitude and geographical phenomena that make the Mediterranean warm at faster rates than the global average. As already pointed out, these underlying drivers are not subject to local control but there are options that are available to mitigate local impacts and to adapt. These include:

- Identifying and following ecosystem changes requires sustained monitoring and research programs. International and interdisciplinary efforts are essential for elucidating the complex responses to climate change and informing adaptive management strategies. Even the most extreme events such as mass die-offs receive limited media coverage, so making data available to the public and policymakers is important.
- The quantity of brine produced from desalination plants is increasing rapidly (Jones *et al.*, 2019), but adverse impacts of their hypersaline discharges on adjacent benthic communities (such as seagrass, coral reef and soft-sediment ecosystems) can be avoided by careful site selection following local monitoring surveys (Roberts *et al.,* 2010). Zero-brine desalination technologies are also being applied.
- A major contributor to marine ecosystem degradation and loss of ecosystem service is the explosion in invasive species. Preventing

further invasions of NIS via the Suez Canal by creating a salinity and temperature barrier from desalination plant discharges along the Canal is proposed as a practical first step towards mitigation.
- Jellyfish are harmful to many human activities through stings, clogging of intakes (e.g. to coastal power and desalination plants), interference with fishing and aquaculture, with significant economic costs. They multiply more rapidly in warmer, less oxygenated and more acidic waters and thus benefit from the changes resulting from warming and acidification. Sewage and agricultural run-off increase the nutrients that promote algal growth which supports jellyfish growth. Turtles are one of the few predators for bigger jellyfish but are themselves at risk from overfishing.

Policy options thus range from conservation to effluent treatment to reduce nutrient input. Malara and Peda (2025) describe the synergistic effects of climate change, marine litter, and overfishing on marine predators in the Mediterranean, which would suggest the inclusion of terrestrial waste disposal (especially for plastics) as a factor affecting the marine ecosystem.

Marine Protected Areas (MPAs) are one response to the pressures from overfishing, but are vulnerable to the wider threats of warming and invasive species. While MPAs have not been designed to be a mitigation measure for climate change, they can, if properly designed and implemented, provide mitigation services as shown in Table 6.2. Surveys have however found that MPAs offer similar protections to invasive species as native species, so their effectiveness in protecting native ecosystems needs to be associated with measures to remove dominant NIS (Giakoumi *et al.,* 2018; Bilecenoğlu and Ertan, 2021). Guidance is offered by Otero *et al.* (2013).

Table 6.2. **Ecosystem services provided by Marine Protected Areas**

Service	Comments
Carbon sequestration	MPAs protect and restore habitats like seagrass beds that absorb and store CO_2.
Protect “Blue Carbon” sinks	Effective MPAs protect other carbon-rich habitats such as macroalgae forests and seafloor sediments, and support the expansion of seaweed farming.
Boosting ecosystem resilience	By reducing pressures (habitat degradation, overfishing, pollution), MPA ecosystems are more resilient.
Supporting adaptation	MPAs can provide habitats for marine life to move to, maintain genetic diversity, and support increased connectivity that allows species to adapt to new conditions.

A 2020 survey of MPAs in the Mediterranean found that, overall, 0.4% of the Mediterranean sea area was covered by some form of MPA designation, but that the most protected category subject to no-go, no-take and no-fishing restrictions (shown in Figure 6.1) covered only 202 km^2, or 0.01% of the total area. In the Eastern Mediterranean, MPAs are mostly along the northern coasts with little protection along the African continent. Monitoring and enforcement was found to be limited in many cases. The areas protected are substantially below the 10% target adopted under the Convention on Biological Diversity and strengthening management and extending the areas protected by MPAs is one effective response to the threats from climate change.

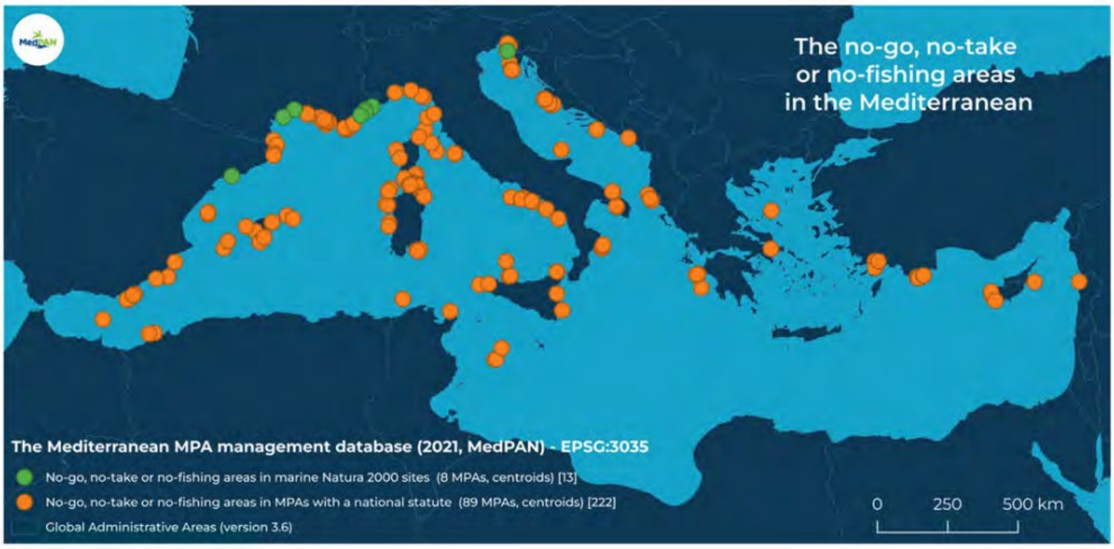

Figure 6.1. **Marine Protected Areas in the Mediterranean (no-go, no-take or no-fishing areas)**. Source: MedPAN/UNEP (2023).

7. NON-INDIGENOUS/INVASIVE SPECIES

The over 1000 invasive species that have entered the Mediterranean have multiple origins (Galanidi *et al.*, 2023) with 340 having come from ships (e.g. ballast water), 150 from aquaculture or aquarium trade releases, with the largest number (500+) having entered via the Suez Canal- a pathway for non-indigenous species (NIS) to enter from the Red Sea and Indo-Pacific waters. These alien species are continuing to displace native Mediterranean ecosystems with one new NIS entering every two weeks (Zenetos and Galanidi, 2020).

The Mediterranean has a high percentage of endemic species (~20%) and they are unable to migrate to cooler waters as the temperature rises, unlike species in the open waters of the Atlantic and the North Sea. This makes them more vulnerable to climate change while the Mediterranean becomes more favourable to tropical species.

Although the dominant route for NIS is the Suez Canal, as yet, no environmental impact assessments have been carried out; neither have any measures been taken to prevent NIS from traversing the Canal. As a result, the number of NIS entering via the canal is likely to continue to increase with the negative impacts of this ‘Lessepsian’ invasion most significant in the Levantine Basin[7], before spreading to other parts of the Mediterranean. Warming favours tropical thermophilic NIS, and some of these have replaced native species, even in Marine Protected Areas, reversing marine conservation efforts and impeding the recovery of economically and ecologically important native species.

The EMME Report reviews the research associated with NIS and the databases that have been established. NIS have negative effects on the marine ecosystem through several mechanisms. They may outcompete native species, consume them, destroy habitats (e.g. by overgrazing the native corals, sea grass or macroalgal zones), bring in new pathogens and reduce ecosystem services such as fisheries, tourism and aquaculture. Jellyfish are particularly problematic since swarms consume all eggs and larvae of native fish, clog nets or water intakes, foul beaches and some (such as Lion or Puffer fish) can potentially harm people (even fatally) if mishandled (Ulman *et al.*, 2024). In some cases, impacts can be positive in terms of creating a new food source. Potential impacts can thus be positive or negative as in Figure 7.1.

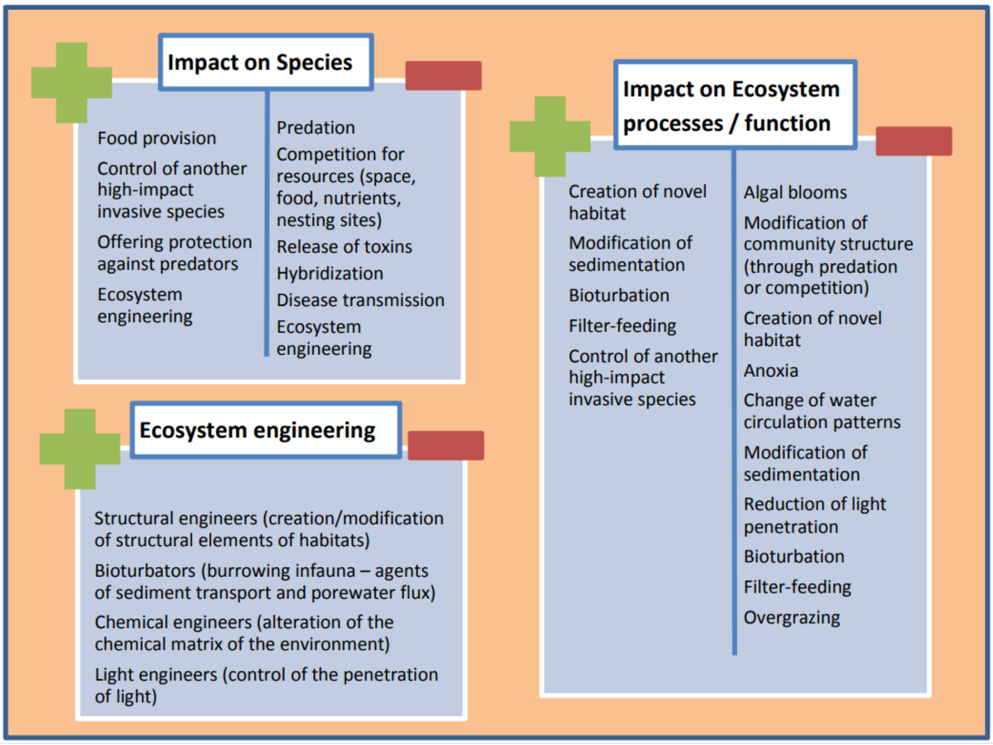

FIGURE 7.1. **Mechanisms by which alien species impact biodiversity.** Green cross: positive impacts. Red minus sign: negative impacts. From Katsanevakis *et al.*, 2014.

[7] EEA (2015) report that the Aegean-Levantine Sea is the most affected by NIS in the Mediterranean, with an annual average of 16 species during the last six-year assessment period (2012-2017).

The EMME Report (Karageorgis *et al.*, 2025) notes that aquaculture and fisheries have been adversely affected through algal blooms, fouling by macroalgae and sessile species, damage to fishing gear or catch, net clogging by jellyfish, and reduced fisheries yields that include the collapse of pelagic fisheries in some areas. Overall, Eastern Mediterranean fisheries have seen a reduced yield of native fishes which has not been offset by harvestable NIS. Examples of NIS with particularly damaging effects are in Table 7.1.

Table 7.1. **Some examples of negative impacts of non-indigenous species**

Species	Negative Impact
Jellyfish *Rhopilema nomadica*	Stings to bathers, clogging of nets
Jellyfish *Mnemiopsis leidyi*	Decline of pelagic fisheries
Silver teeth toadfish *Lagocephalu*s *sceleratus* Lionfish *Pterois* spp	Direct toxic effects or bites on humans (fishers, divers, bathers, consumers etc,)
Spinefoot rabbitfish (*Siganus luridus* and *Siganus rivulatus*) Sea-urchin *Diadema setosum*	Grazing of macrophytes and destruction of habitat
Green Algae *Caulerpa cylindracea*	Colonization and alteration of native assemblages

In terms of potentially positive effects, some NIS could provide a food resource for native fish, may be harvestable commercially, or could create a new habitat. These are however observed less often than the negative effects. Another consideration is that the rise in temperatures is causing temperature-sensitive native species to decline or disappear, potentially vacating ecological niches that can be filled by NIS.

As sea temperatures continue to rise, NIS already present in the Eastern Mediterranean are expected to continue to spread and affect the marine ecosystem and its services. The IMO have developed regulations to address ballast water as a route for the arrival of additional species, so enforcement of these can reduce the spread via shipping, as would development of ship hull cleaning technologies, protocols and regulations. Moreover, FAO and others are seeking to mitigate the impacts of NIS through adapting fishing practices and markets to exploit edible species. Innovating applications (such as marine 'leather' from puffer fish) are also emerging.

As already mentioned in Section 6, one option to slow new arrivals would be to create salinity or other barriers along the Suez Canal. At the same time monitoring should detect any new arrivals, and the spread of those already present, as is carried out by the FAO's General Fisheries Commission for the Mediterranean (GFCM).

For the most damaging species, means of removal, control and, if possible, eradication could be explored. Exploiting species may be possible as a seafood dish, as fishmeal for the aquaculture industry, or even for pharmaceutical uses where unique chemicals are involved. Some successes have been recorded through the GFCM– for example the Silver Teeth Toadfish has become a delicacy in Cyprus; Turkish fishers are developing new markets for species like lionfish, sea urchins and Randall's seabream; Rabbitfish, Red Sea goatfish and lionfish are being caught and sold for human consumption in Lebanon; in Tunisia, blue crabs that came from the Atlantic are caught and sold in new markets. Research is underway exploring uses for jellyfish biomass in food and non-food products.

Tiralongo *et al*. (2025) point to recent work on Mediterranean bio-invasions from lionfish, the seaweed *Caulerpa cylindracea* and rabbitfish where understanding lifecycles and habits could identify custom management solutions. For example, lionfish can be contained through frequent removal by scuba divers and by developing a recreational and commercial market. Rabbitfish were sensitive to chemical alarm signals, so a chemical approach could be productive, However, these examples suggest that generalized solutions are unlikely, and place a high demand on research to fully understand the target species' life cycle and behaviour.

8. AQUACULTURE

Aquaculture is an increasingly important economic sector with FAO estimating that the value of this sector in the Eastern Mediterranean is ~7 billion USD. Production is already double that of caught fisheries and expected to continue growing, while the yield from the latter is expected to remain steady or decline. Up to 63 species have been farmed in the region, but four species make up ~ 80% of production (Nile tilapia, mullets, gilthead seabream and European seabass). Two countries (Egypt and Turkey) in 2023 made up 87% of the total production in the Eastern Mediterranean (Figure 8.1).

Sicuro's (2024) study of Mediterranean aquaculture found that it could grow 5-fold or more from 2020's production of 2.8 million tons. European seabass and gilthead sea bream will remain preferred species and Nile tilapia farming will also increase. Aquaculture production in Mediterranean countries is mainly influenced by the historical presence of aquaculture in each country and secondarily by the number of farmed species. Interestingly, the pioneer aquaculture countries have maintained their prominent position until 2020 (Sicuro, 2024).

The optimum temperatures for the main farmed species lie between 22-28 ^{o}C with survival tolerance ranging from 32-34 ^{o}C. Recent temperature rises to 28-30 ^{o}C in summer is thus taking the species outside their optimal range leading to physiological stress and lower growth which, together with higher costs on disease prevention and treatment, is reducing economic viability. Fish farmers are already responding by moving operations offshore to cooler waters, reducing fish stocking densities to improve oxygen flow, and exploring innovative indoor farming systems.

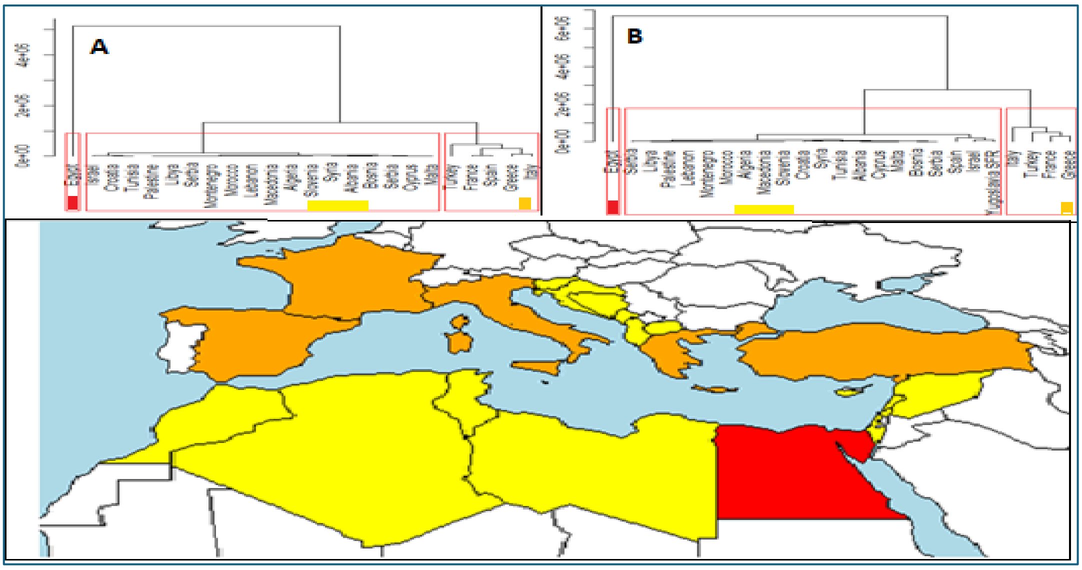

Figure 8.1. **Map of Mediterranean aquaculture productions**. A: cluster obtained considering the cumulate productions from 1950 to 2020; B: cluster obtained considering cumulate productions from 2016 to 2020. Geographical map refers to total cumulate productions (cluster A). Source: Sicuro (2024).

The littoral ecosystems that adjoin many aquaculture projects are at greater risk from climate change and associated impacts than open marine ecosystems (Hassoun *et al*., 2025). Warming and non-indigenous species have led to the complete removal of canopy-forming macroalgae along broad extents of the coastline, and formerly dominant marine forests have been replaced by algal turf or reef barren, so that coastal habitats have become impoverished in terms of primary productivity, biomass, and biodiversity. Seagrass meadows and seaweeds are also at risk with marine heatwaves and overgrazing by NIS among the contributing factors.

The EMME Report pointed out that aquaculture faced threats that will require flexibility in the industry for mitigation and adaptation. In some areas, fish may benefit initially from the ocean warming in terms of their rate of growth, but any benefits will be quickly lost as the intensity and frequency of extreme events causes substantial mortalities, escapees and losses in biomass. Coastal aquaculture is also vulnerable to harmful algal blooms that reduce oxygen levels, and may also be toxic, causing mass mortalities. 16% of aquaculture's value (about 1.1 billion USD) is produced in the brackish water of lagoons susceptible to inundation as the sea level rises (Soria *et al*., 2022).

Warming also favours the growth of pathogens and parasites, and Cascarano *et al.* (2021) found that temperature increases lead to significant increases in disease outbreaks within aquaculture systems. Warming may boost the rate of disease transmission and its virulence by increasing pathogens' fitness in weakened hosts (Rigos *et al.*, 2026), with almost 28 microbial diseases in European finfish farming potentially facilitated by climate warming. While each main disease has a specific temperature range, bacterial, viral and parasitical infections are expected to increase with temperature (Sea Bream are particularly susceptible). Synergistic effects may also come into play through combinations of temperature with other drivers such as dissolved oxygen, acidification and algal blooms, further impacting the profitability of farming.

The EMME Report reviewed the extensive literature and noted that thermal tolerances for the main species are well understood and may offer some potential to exploit warmer temperature to increase production at first. Models suggest that farm profitability under IPCC RCP4.5 and RCP8.5 scenarios for European seabass and meagre may benefit in terms of growth, but any benefits will be largely offset by the negative effects of extreme events like marine heatwaves and storms. Various means of increasing heat tolerance are under research and development (such as by early life stages exposure, assisted evolution, and restoration of temperate and tropical reefs with heat-tolerant individuals). Acidification is expected to pose threats to bivalve farming but seems to have little effect on adult fish.

Adaptation and mitigation strategies to counter the impacts of climate change through increased temperature, eutrophication, harmful algae blooms, water stress, sea level rise, acidification and diseases have been proposed (e.g. Rosa *et al.,* 2012), while Atalah *et al.* (2024) examined how aquaculture can adapt to increased intensity and frequency of marine heatwaves such as that in 2022 when a temperature anomaly of up to 4.2 ^{o}C lasted all summer. For seabream and seabass, net pens should be submerged to depths of around 20 m and 15 m, respectively, ideally in the second week of July. Innovative mitigation tools, such as fish selective breeding, epigenetic programming, the development of new vaccines, and alternative treatments, may prove essential, and a range of measures have been proposed (e.g. Pham *et al.*, 2021) including breeding programmes to identify temperature resistant fish strains; seeking new species with high thermal tolerance; developing new farming technologies, vaccines and new disease prevention methods.

Adapting to future extremes thus demands a multi-faceted approach encompassing scientific research, technological innovation, regulatory measures, and industry collaboration. Examples are the FAO/GFCM centre for aquaculture demonstration centres and the Hellenic Centre for Marine Research's Institute of Marine Biology, Biotechnology & Aquaculture.

Aquaculture producers may also benefit from shifting to aquaculture techniques that are less vulnerable or are more resilient to a changing environment. For example, the Integrated Multi-trophic Aquaculture (IMTA) system cultivates species from different trophic levels so that waste and uneaten feed from one species can supply nutrients and food to another species- a more circular system that is more environmentally friendly and can be more resilient to changing climate conditions (e.g. Nissar *et al.*, 2023).

Finally, the rapid growth of aquaculture envisaged by Sicuro (2024) raises environmental concerns, including waste accumulation from uneaten feed and metabolic processes, which can lead to local eutrophication and affect water quality and benthic ecosystems. Greece now requires environmental impact monitoring on fish farms, and an analysis of environmental impacts of 106 marine fish farms in Greece by Faulwetter *et al.* (2025) showed effects to be largely local with organic and nutrient enrichment detected up to 130 m from the fish farm and impacts on benthic macrofauna limited to tens of meters from cages.

9. INTERNATIONAL COOPERATION

The Eastern Mediterranean is, from an ecosystem perspective, borderless, despite there being many countries around it. Individual national surveys and research recognise the border-less nature of the marine environment and some coordination does take place, with scientific data shared openly through reports and publications. Nevertheless, the EMME report identified a lack of data on many aspects. Current shortcomings include:

- **Lack of consistent, long-term data:** A significant challenge is the absence of regular, structured, and long-term monitoring programs for both physical parameters and biodiversity.
- **Limited resources:** Insufficient human and financial resources often hamper observation capabilities.
- **Methodological gaps:** There are persistent gaps in understanding the resilience and adaptation capacities of ecosystems and the specific impacts on different species and habitats.
- **Harmonization of protocols** (and inter-calibration) among countries to get comparable results

There are many research and monitoring resources in Eastern Mediterranean countries and some can be found in a list of institutes involved in marine research compiled by the Commission Internationale pour l'Exploration Scientifique de la Méditerranée (https://www.ciesm.org/online/institutes/IndexInstituts.htm).

Coordination and burden-sharing through collaboration are important and mechanisms exist for collaboration at both government level and between individual institutes. One example of EU-led coordination was the SUPREME program from 2017 to 2019 based on the implementation of Maritime Spatial Planning in EU Member States within the Eastern Mediterranean. However many research and monitoring activities still rely on individual national programmes and are subject to budgetary constraints and pressure from competing national demands.

The broad focus of the recent EU Mediterranean Pact offers the opportunity to coordinate the necessary oceanographic and marine biology research identified in this report. Work is also in progress under the auspices of the **Barcelona**

Convention on achieving Good Environmental Status which brings together Mediterranean countries.

Cooperation between Institutes is also underway and forms the potential foundation for further collaboration. The **MedJICARP Project** involves nine scientific institutions from eight countries (coordinated by the Oceanography Centre in Cyprus and including the Cyprus Marine and Maritime Institute, the HCMR in Greece, and the National Institute of Oceanography and Fisheries in Egypt); the **EMS FORE (Eastern Mediterranean Sea Future Ocean Research)** is a partnership between Germany's GEOMAR and the University of Haifa in Israel; the **CIESM (The Mediterranean Science Commission) PartnerSHIPS Program** fosters partnerships between scientists, governments, and shipping companies to use commercial ships for cost-effective water monitoring. **Hellenic Centre for Marine Research (HCMR) also** participates in numerous EU projects and international networks to advance Eastern Mediterranean oceanographic research. Mechanisms thus exist for strengthening monitoring and research to fill the data gaps identified in this report.

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11. GLOSSARY

AASSA	Association of Academies and Societies of Science in Asia
CCI	Climate Change Initiative
CIESM	Commission Internationale pour l'Exploration Scientifique de la Méditerranée
DO	Dissolved Oxygen
EASAC	European Academies Science Advisory Council
EMED	Eastern Mediterranean
EMME	Eastern Mediterranean and Middle East
FAO	Food and Agriculture Organization
GEOMAR	Helmholtz Centre for Ocean Research Kiel
GFCM	General Fisheries Commission for the Mediterranea
HMRC	Hellenic Centre for Marine Research
IAP	Inter-Academy Partnership
IMO	International Maritime Organisation
IMTA	Integrated Multi-trophic Aquaculture
IPCC	Intergovernmental Panel on Climate Change
MedECC	Mediterranean Experts on Climate and Environmental Change
MedPAN	Network of managers responsible for Marine Protection Areas
MHW	Marine Heat Waves
MPA	Marine Protection Area
NASAC	Network of African Science Academies
NIS	Non-Indigenous Species
RCP	Representative Concentration Pathway
SLR	Sea Level Rise
SST	Sea Surface Temperature
UfM	Union for the Mediterranean

This report has been drafted with input from invited national experts and experts nominated by Science Academies at an in-person workshop held on November 21-22, 2025, at the Cyprus Institute (Nicosia, Cyprus). A draft report was reviewed in a second workshop held on-line on February 3, 2026.

The Eastern Mediterranean is warming significantly faster than the global average. The marine environment—one of the region's most valuable shared resources—is increasingly exposed to interacting pressures from warming, acidification, sea-level rise, and biological invasions.
This report synthesizes current scientific understanding and identifies practical priorities for adaptation and resilience.

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