# Policy Brief 1
# CLIMATE EXPOSURE OF EUROPEAN MARINE AREAS: HOTSPOTS AND REFUGIA

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## HIGHLIGHTS

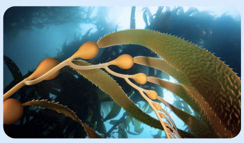
Ocean warming, deoxygenation and acidification are the main stressors that affect marine habitats driving losses in biodiversity and threatening ocean food production for human communities. The Intergovernmental Panel on Climate Change (IPCC) Special Report on the Ocean and Cryosphere in a Changing Climate (SRO CC) underscored the critical impacts of climate change on the planet's marine ecosystems. The oceans will continue to be altered this century, and successful climate adaptation and mitigation measures are urgently needed.

Effective actions to adapt to the ongoing changes in our climate require detailed information on the physical and biogeochemical changes expected in our oceans. Current projections, such as the Coupled Model Intercomparison Project (CMIP6), do not adequately resolve details of changes in regional and coastal zones of marine habitats, areas where strategic planning to sustainably manage marine resources and ecosystem services is most needed.

To offer the best possible information on the impacts of marine climate change for decision making, **FutureMARES** developed projections that provide an assessment of local-scale impacts of climate change in coastal zones and shelf seas (Kristiansen et al. 2024). The work focuses on the three main stressors impacting marine ecosystems and provides monthly values for 1993-2100 at a resolution of about 8 km for four European regions: North Sea, Baltic Sea, Bay of Biscay and Mediterranean Sea.

These projections serve as the basis to analyse the potential success of a range of marine Nature-based Solutions (NBS), identify future climate change hotspots as well as refugia for sensitive species, and support Nature-inclusive Harvesting (NIH) of living marine resources.

This policy brief is based on the results of statistical down-scaling of climate models for application to European regional seas and coastal zones. The results allow us to better understand expected climate impacts and identify climate hotspots and refugia for sensitive species, across a range of scenarios and climate models. The projections are important for successful planning of NBS to help safeguard marine biodiversity and ecosystem services in a future climate.



**FutureMARES** (Horizon2020) provides socially and economically viable research and strategies that support Nature-based Solutions (NBS) for climate change adaptation and mitigation across European, Central and South American seas. **FutureMARES** conducts its research along three future climate change scenarios:

**Global Sustainability**
SSP1-2.6
Low challenges to mitigation and adaptation

**National Enterprise**
SSP2-4.5
High challenges to mitigation and adaptation

**World Markets**
SSP5-8.5
High challenges to mitigation, low challenges to adaptation

# KEY STATEMENTS

- Warming and acidification were projected for all European Seas. While spatial patterns vary between the pressures, the combined pressures highlight the Mediterranean Sea and subpolar regions along the coast of northern Norway as hotspots, while the temperate mid-latitude shelf seas are less affected.
- Warming is particularly high in waters along the North African and Norwegian coasts, while ocean acidification is highest in the Bay of Biscay, and the southern Adriatic and the Aegean Seas.
- Future amounts of deoxygenation (decreases in dissolved $O_2$ concentrations) are more uncertain than warming or acidification but losses in $O_2$ are expected to be highest in deeper parts of the Western Mediterranean Sea due to reduced vertical mixing of waters.
- Projections for the Baltic Sea are particularly uncertain. This semi-enclosed basin is poorly represented in the underlying coarse-scale global models and these waters are sensitive to terrestrial inputs and coastal processes not well represented in models.
- Global net zero $CO_2$ emissions may be achieved in 30 to 50 years in optimistic IPCC scenarios, while still leading to a rise in the combined impact of warming, acidification, and deoxygenation across all European Seas.
- This work provides new information on the extent and uncertainty of environmental change at scales that are relevant and accessible for local to regional management of ecosystem services related to NBS and NIH.

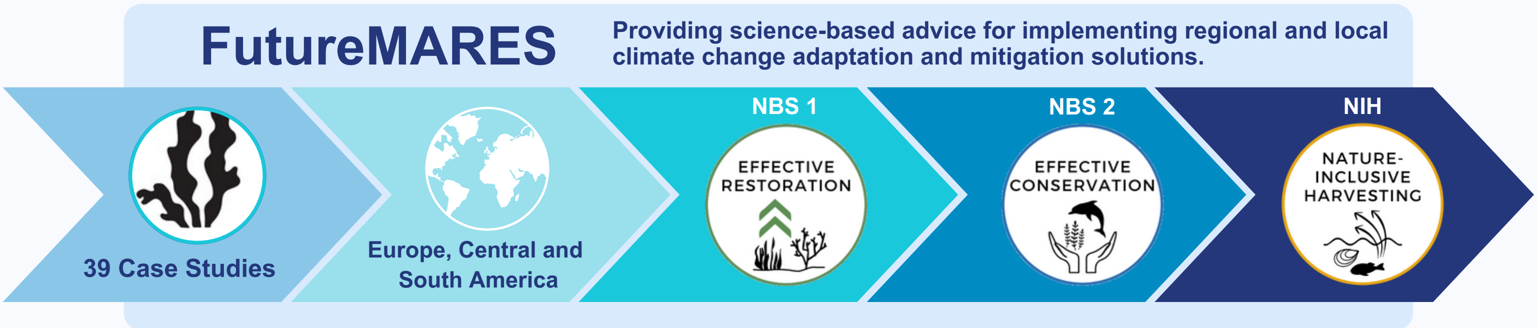
# CONTEXT & BACKGROUND

The Climate Change report (IPCC 2023) indicates that global warming will continue to increase in the near term (2021–2040) mainly due to increased $CO_2$ emissions. Consequently, ocean acidification and deoxygenation will continue to rise. This can have large impacts on other physical and biological processes underpinning the structure and function of marine ecosystems. Historical ocean observations highlight that the pace of current changes is higher than previously expected and that changes can manifest in a range of different ways.

Even if greenhouse gas concentrations in the atmosphere stabilize, the IPCC results indicate that these changes will continue in the long term, posing a challenge for effective actions to increase ocean biodiversity and sustainable management of natural living resources.

Many governments currently focus on NBS such as habitat restoration and adaptive marine spatial planning as an essential part of their climate adaptation and mitigation activities. However, studies on the impacts of climate change on marine ecosystems require fine-scale projections to support the planning and implementation of these and other mitigation and adaptation measures, as well as NIH.

The comprehensive CMIP6 initiative provides global climate models that simulate the physical, biological, and chemical processes within the atmosphere, ocean, ice, and land, and how these processes combine to affect the global climate. These models provide possible climate trajectories for the future, but they lack precision for coastal environments, essential areas for developing and implementing climate change adaptation and mitigation plans.



# KEY RESULTS

## 1) Improved modelling methodology.

**FutureMARES** applied a statistical bias-correction and downscaling of the global CMIP6 projections. Bias-correction minimizes the errors between observed and modelled climate data for a specific control period, while the downscaling establishes an empirical relationship between historical fine-scale features and large-scale climate patterns and trends. This statistical connection is then applied to make projections of future climate at smaller (local) scales. These new climate projections allow other models and strategic applications to better understand future impacts on marine species, communities, and ecosystems.

## 2) Climate change impacts on European waters at the end of the century - Hotspots and refugia.

Projections of the combined climate change-induced ecosystem stressors show how global-level changes in climate forcing and interacting regional hazards (e.g. eutrophication) cause local perturbations to environment characteristics (e.g., warming, acidification, deoxygenation, stratification, nutrient dynamics). These changes can have substantial consequences for the ecology and biodiversity of shelf seas and coastal habitats.

Warming will continue to cause geographical shifts in species distributions and may induce habitat compression when combined with topographical barriers or other stressors. Warming favors the invasion of alien species, induces metabolic stress, reduces body-size and alters reproductive patterns, increases the risk of bacterial or viral infections in organisms, and generally disrupts existing ecosystems. Ocean acidification strongly affects organisms that rely on calcium carbonate in their structural components and can significantly increase the metabolic energy demand for marine organisms via acid-base regulation, particularly in combination with warming (Alter et al. 2024). Deoxygenation leads to increasing areas of hypoxia, seriously limiting or damaging all organisms whose metabolism relies on oxygen.

Absolute thresholds for ecosystem stress are difficult to establish because organisms have different sensitivity depending on, for example, adaptation to their local conditions. In general, therefore, stress may be best expressed by the levels that future change exceeds local, natural variability.

# Policy Recommendations

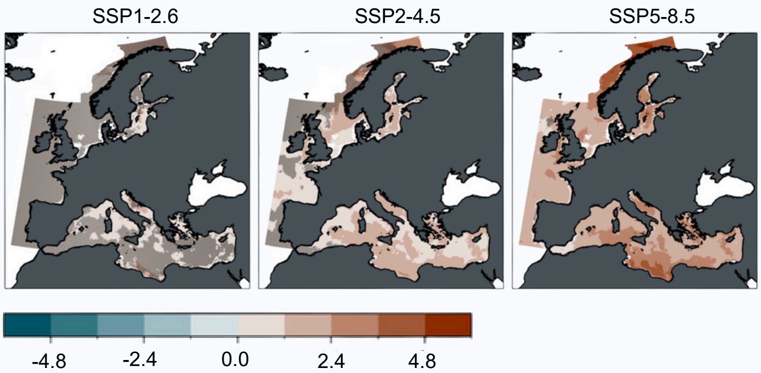
- Climate-driven projections for different scenarios of future environmental stress indicate the importance of implementing global mitigation policies to lessen the strain on ecosystems, particularly by reducing exposure to severe pressures.

- In a global context where actions to promote climate resilience are more urgent than previously estimated (IPCC 2022), detailed maps showing the distribution of these stressors across European Seas provide valuable insights for local adaptation policies, supporting spatial planning and implementing ecosystem-based management strategies.

- Identifying areas projected to have very high and very low (if any) levels of environmental stressors informs decisions on where to establish new sites for conservation (e.g. Marine Protected Areas) and habitat restoration, and the effective management of existing sites to better safeguard vulnerable species and habitats.

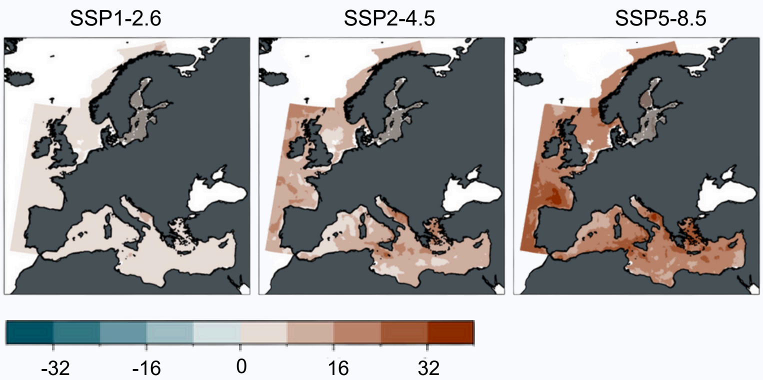
**Exposure to warming, acidification and deoxygenation expressed relative to the exposure to natural variability in each location. Model uncertainty is represented by shaded areas.**

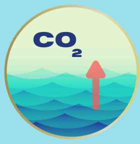
| Global Sustainability | National Enterprise | World Markets |
|---|---|---|




## WARMING EXPOSURE

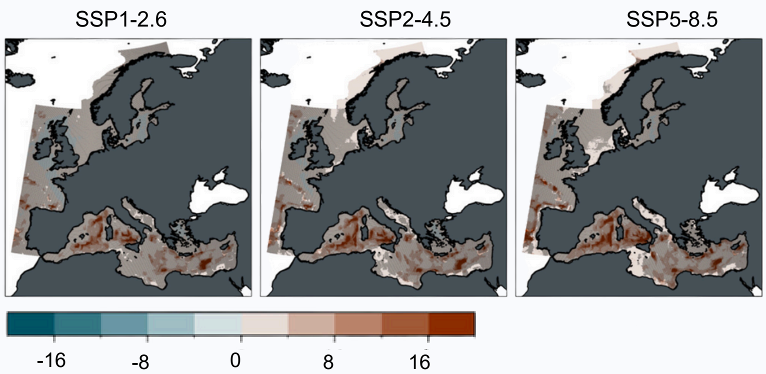
The coastal waters of Norway (Norwegian and Barents seas) and the North African coast (Mediterranean Sea) show the highest warming exposure, under the unmitigated conditions scenario – World Markets. However, warming decreases significantly under the National Enterprise scenario. Under the Global Sustainability scenario, changes are small and are less than the level of uncertainty of the ensemble.




## ACIDIFICATION

The Iberian Peninsula, Sicilian Strait, Southern Adriatic, and the Aegean Seas have strongest exposure to acidification. The indicator is particularly high (up to 32 times the natural variability) under the World Markets scenario.





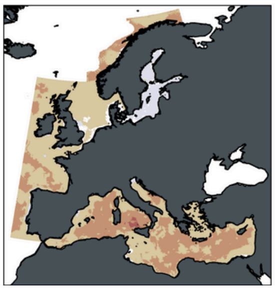
## DEOXYGENATION

Appears strongest in various locations of the Mediterranean Sea, but the pattern for this indicator is very complex and uncertain for most regions across all scenarios since oxygen cycles are not well represented in the current generation of Earth System Models (Takano et al. 2023).

**Overview of hotspots and refugia of combined climate change-induced ecosystem stress of warming, acidification and deoxygenation in the form of exposure categories, for the end of the century.**

**Global Sustainability**

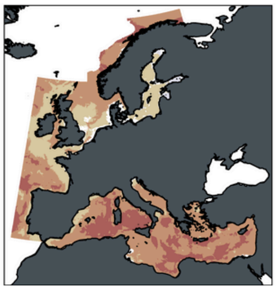
SSP1-2.6



Only categories 1 and 2 are present.

**National Enterprise**

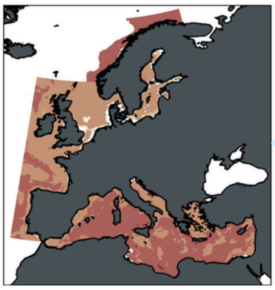
SSP2-4.5



Exposure levels gradually increase. The maximum level reached is category 3, but covers less areas than in the World Markets Scenario.

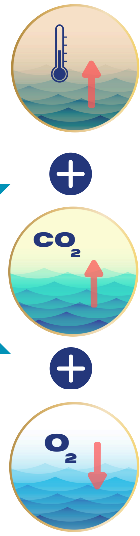
**World Markets**

SSP5-8.5



All European waters are subjected to stress of at least category 2. All of the Mediterranean and the coastal waters of the Norwegian and Barent Seas and part of the North-East Atlantic present at least category 3.

**End of Century**
*Year 2100*




## Exposure Categories (year 2100)


- Change exceeds natural variability
- Change exceeds twice the natural variability
- Change exceeds four times the natural variability
- Change exceeds eight times the natural variability

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The dataset was generated using E.U. Copernicus Marine Service Information and algorithms from Actea Inc. (actea.earth); Version 1 was distributed on May 24, 2022, and version 2 was released on March 7, 2024. The datasets are distributed under Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License.

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