Multiple Pressure Exposure and Mitigation Potential of Europeans Seas under the Climate Hazard

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The knowledge of **exposure levels** of marine habitats to **environmental pressures** under climate change is **fundamental for ecosystem-based management and the assessment and planning of NBS**.

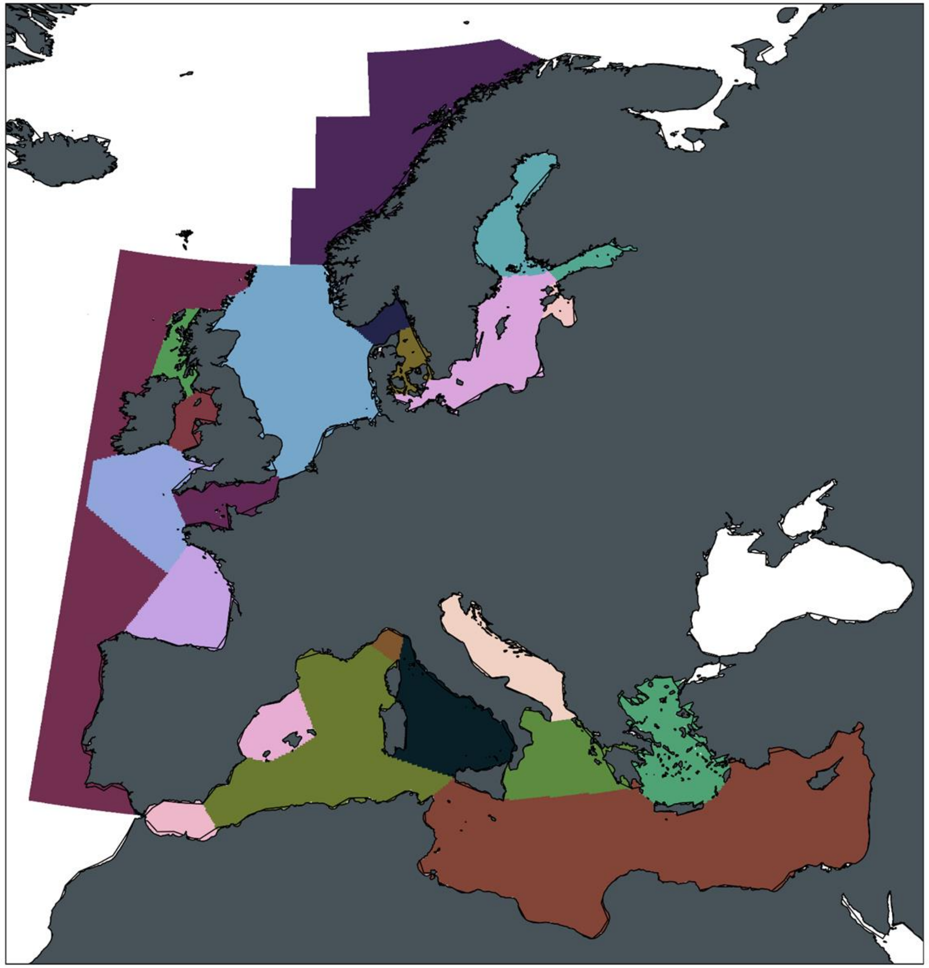
Some information available for specific species in specific locations informing on tolerance intervals and thresholds of resilience.

Thresholds established for a specific location and species cannot be readily extrapolated to other contexts in order to derive a broader picture of hotspots and refuges of marine habitats under climate change.

Environmental data with adequate uncertainty constraints, particularly for future conditions, is available mostly at coarse scale, insufficient to inform ecosystem management adequately.

We propose a generalised approach to define and compare the **environmental pressures** of warming, acidification and deoxygenation across the European Seas at local to regional level by **relating the changes in pressure indicators to the natural variability of the system.**

European Seas (IHO areas)



Analysis based on Statistically Downscaled Ensemble of CMIP6 ESMs and CMs

Ensemble in a nutshell:

- 5 models for a total of 7 realisations
- 5 variables: T, S, O2, pH, Chl
- 3 depth levels (surface: 5m - subsurface: 25m - sea floor)
- 3 scenarios: SSP1-2.6, SSP2-4.5, SSP5-8.5
- Monthly resolution

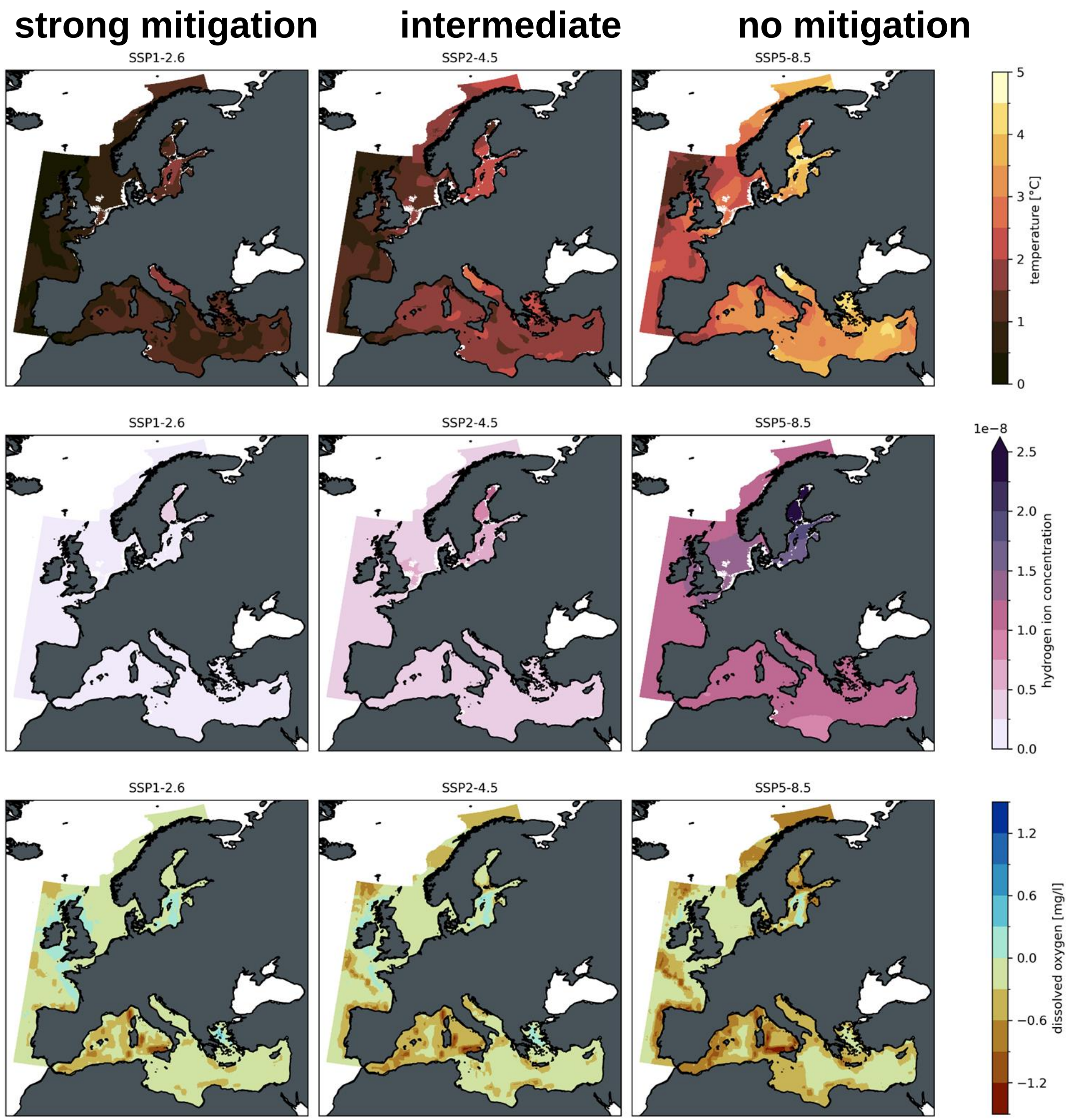
(Kristiansen et al., Scientific Reports 2024, doi:10.1038/s41598-024-51160-1)

Subset chosen for this analysis of exposure to ecosystem pressures:

Warming	Acidification	Deoxygenation
subsurface temperature	subsurface pH (reconverted to H^+ concentrations)	seafloor dissolved oxygen concentrations

This analysis mostly focuses on ensemble medians.

Study Area & Data



Warming is present across the entire domain and all scenarios.
Largely **below 1.5 °C for SSP1-2.6** and **mostly above 3 °C for SSP5-8.5** (wrt present day T).

Acidification is present across all European Seas and fairly homogeneous.
Hydrogen ion concentrations are **2-4 times higher under unmitigated conditions than under mitigated conditions**.

Deoxygenation more heterogeneous. mostly below 1 mg/l with some areas being subject to slight oxygen increase).
Oxygen levels consistently decrease with decreasing mitigation levels.

Baltic Sea results highly uncertain due to importance of unresolved coastal processes missing in underlying Eart System Models

Future Change of Pressure Variables

Aim: Define an indicator of exposure to ecosystem pressure enabling comparison across different pressures at different locations that is more directly related to the stress on the ecosystem.

Approach: Normalise the change occuring over the period of interest by a measure of the natural variability of the system taking into consideration the "natural exposure" in a given location as an indicator for local resilience at the system level.

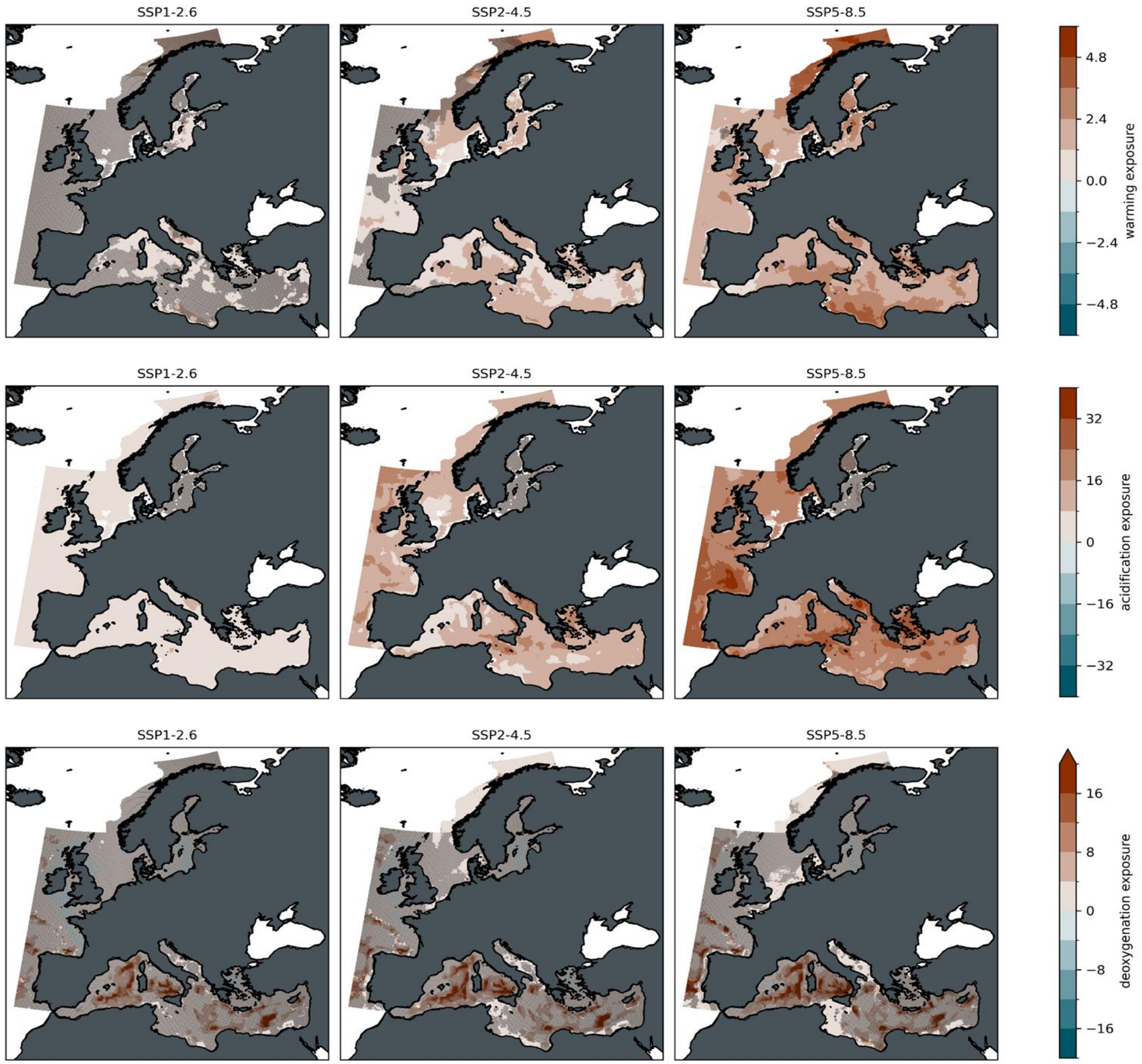
$$E_{\text{pressure}} = \frac{abs(change)}{variability}$$

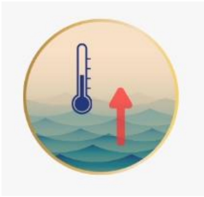
change: difference between means of far future (2081-2100) and recent past (1995-2014) values.

variability: distance of 97.5th/2.5th percentile to the median of the local detrended time series of monthly anomalies for pressures of increasing/decreasing change.

Exposure Maps

strong mitigation | intermediate | no mitigation





Exposure to **warming** up to **twice the natural variability** under **unmitigated** conditions.
Warming exposure decreases with mitigation to well below 1 under strongly mitigated conditions that do not emerge from model uncertainty for most of the domain.

Acidification levels are **significant** with respect to model uncertainty **across the entire domain.** Exposure is particularly high for this indicator (up to 32 times the natural variability and more under unmitigated conditions).

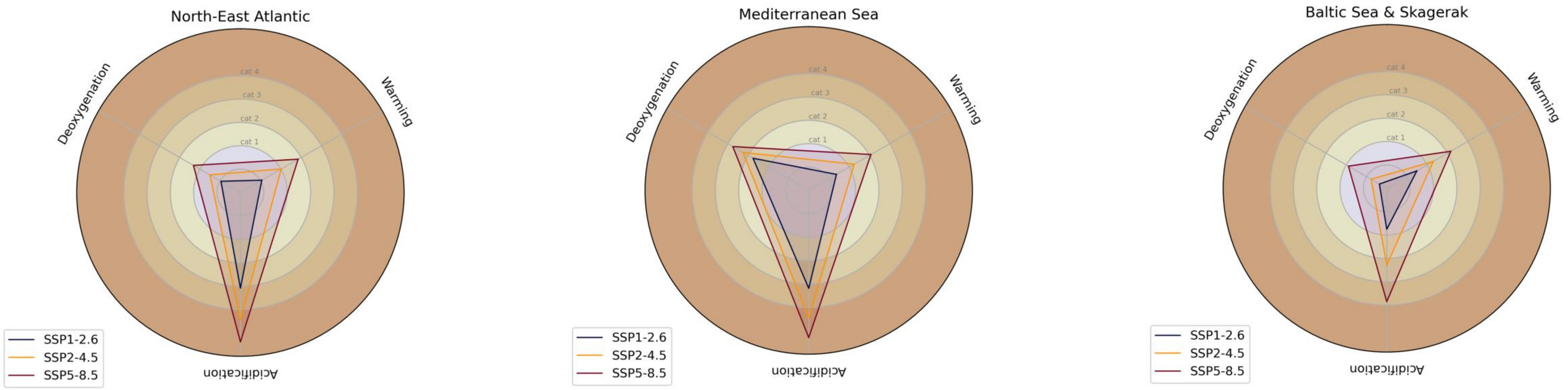
Deoxygenation is **heterogeneous** and **more uncertain** for most of the domain across all scenarios.
Highest levels occur in distinctive parts of the Mediterranean Sea.

For an equilibrated compound indicator of the different stresses given the different levels of natural variability, the indicator levels are further classified into categories of stress applying a logarithmic scale of base 2:

$$C_{\text{pressure}} = \log_2(E_{\text{pressure}})$$

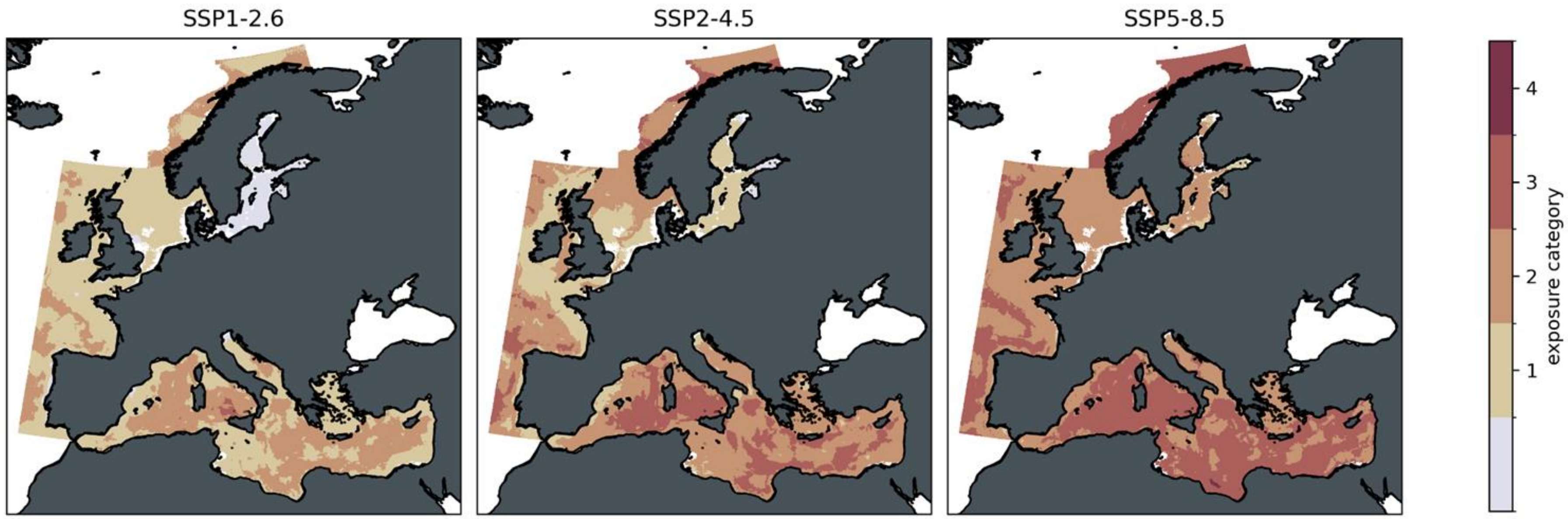
Category 1	Change exceeds natural variability
Category 2	Change exceeds twice the natural variability
Category 3	Change exceeds four times the natural variability
Category 4	Change exceeds eight times the natural variability

Radar plots of exposure to ecosystem stressors allowing for cross comparison across pressures, regions and scenarios



- Illustration of relative importance of pressures across regions and the varying impact of mitigation.
- **Acidification** is generally the **strongest** pressure
- **Mitigation effort** consistantly and substantially **alleviates pressure** across regions and variables

Combined ecosystem stress of warming, acidification and deoxygenation



Under **unmitigated change** the entire domain is subject to stress of **at least category 2**, virtually the **whole Mediterranean and Norwegian Sea** and part of the Northeast Atlantic reach **category 3**.
Exposure levels are **gradually decrease with increasing mitigation**. The maximum level reached in SSP2-4.5 is category 3. In the **strongly mitigated** scenario, **only category 1 and category 2** are present.

The **Mitigation Potential** of warming, acidification and deoxygenation shows how increases in an ecosystem pressure can be avoided by **global** climate mitigation policy.

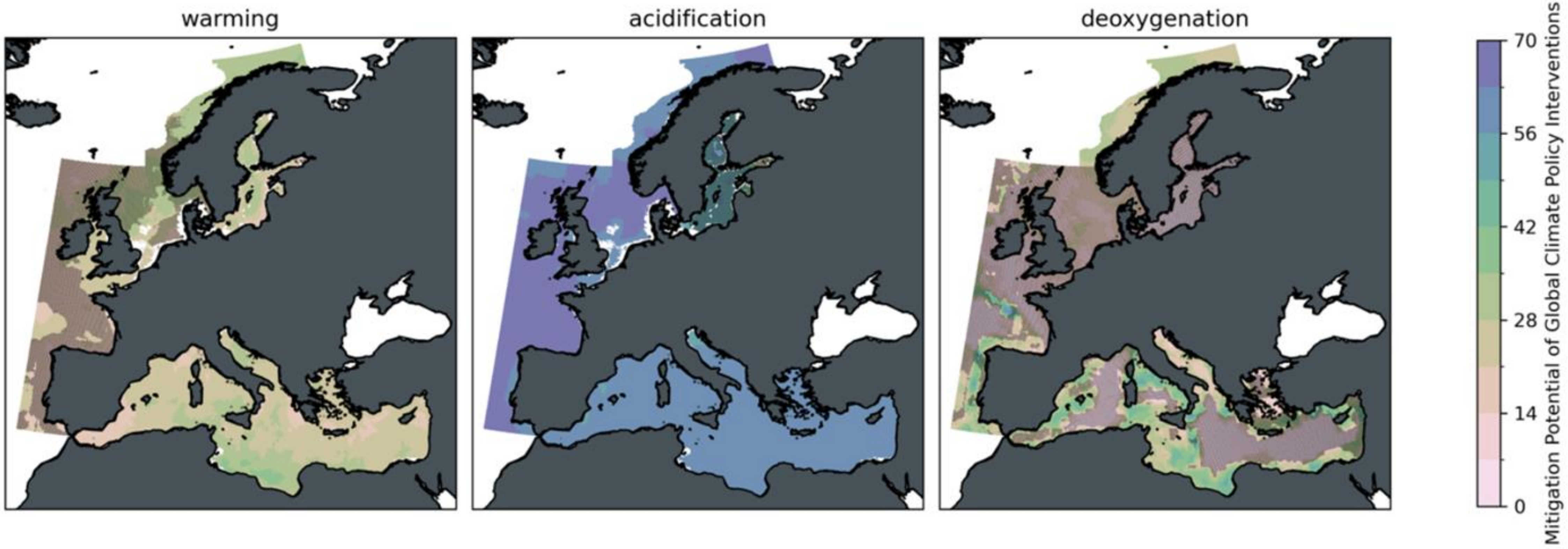
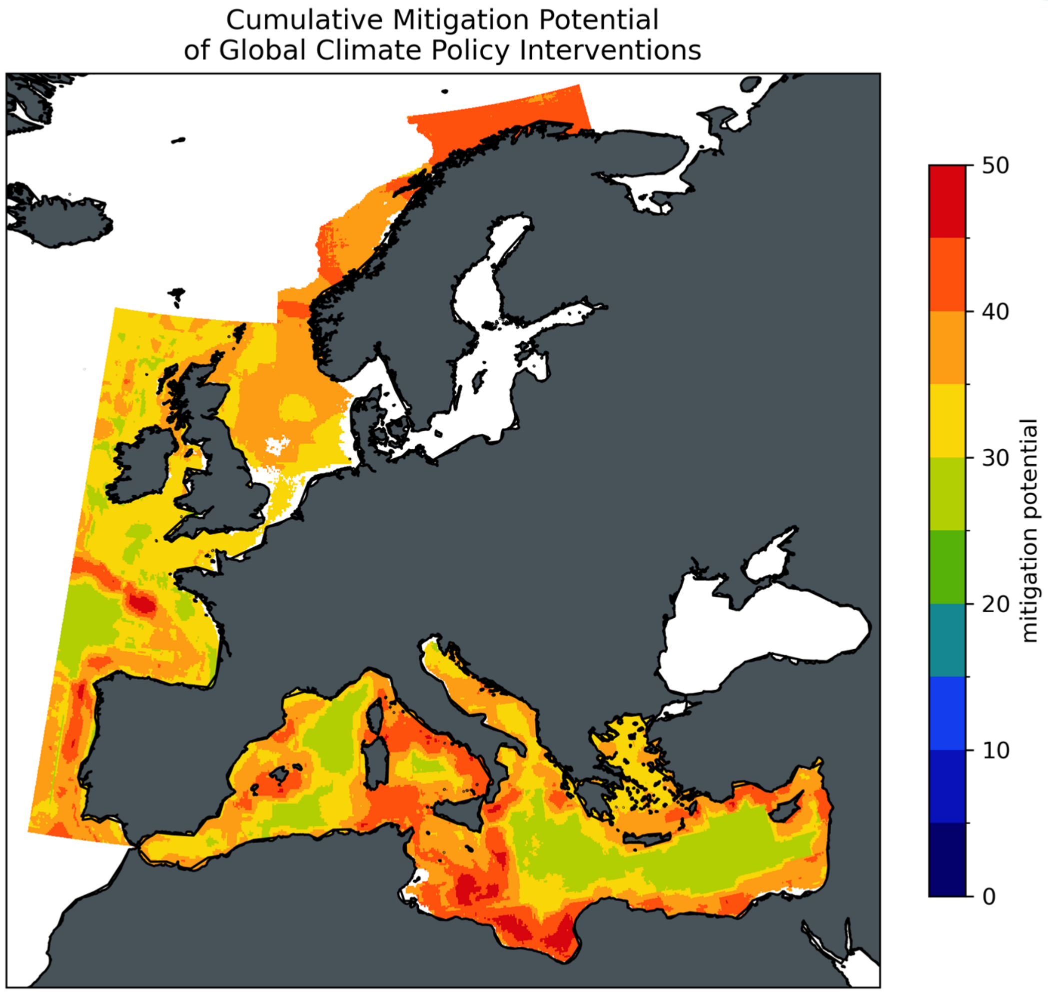


Figure 1.3-7: Mitigation potential for individual stressors. Shading indicates locations where model uncertainty exceeds mitigation potential.

Cumulative Mitigation potential is generally >25% throughout most of the area. Areas that are benefitting most from global climate mitigation policies (**levels more than 40%)** are in the **central Mediterranean, Tyrrhenian Sea, Norwegian Sea,** along the **Eastern Mediterranean coast** and **along the shelf break.**

Even under the greatest mitigation efforts **no more than 50%** of the **cumulative ecosystem pressure** can be **recovered by** the end of the century**.**



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ADVANCING OCEAN PREDICTION SCIENCE FOR SOCIETAL BENEFITS

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