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Policy Brief

**How a network
of representative
biodiversity areas
supports Marine
Spatial Planning
in Europe with
regard to biodiversity
and blue carbon**

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AREAS
EUROPE** **PA**



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Overview

This document presents policy recommendations for stakeholders of *MPA Europe* on how to use our analysis and results of standardised environmental and species distribution data, mapped distribution of organic carbon content in the seabed, and representative biodiversity areas, which show an optimal network for Marine Protected Areas (MPA) in science-based marine and maritime spatial planning (MSP) in Europe.

Recommendations are particularly relevant for our principal stakeholders, the European Commission (EC), the Regional Seas Conventions OSPAR, HELCOM, UNEP and Black Sea Commission, and Member States, in addition to national research institutes, and the European Environment Agency.

Scientific results

The *MPA Europe* project mapped a geographically optimal, ecologically coherent, network of Representative Biodiversity Areas (RBAs) across Europe's seas at a spatial resolution of ~5 km (Figure 1), at European, marine region and country level^{1, 2, 3}. This is based on the geographic ranges of over 10,000 species which represented the range of habitats, ecosystems and biogeographic provinces in the region, including marine species listed in the Birds and Habitats Directives, endangered species and species endemic to Europe. Where isolation occurs as in the Mediterranean and Macaronesian islands, endemic species may evolve; thus, these areas were highly prioritised by the *MPA Europe* RBA². The top 10%, 30% and 50% of this network could include 55%, 79% and 91% of all species in the region respectively, with similar percentages for threatened species. Over 80% of the species that form habitats for others, including seagrasses, kelps and corals, were well-represented in 10% of the RBA^{1, 2}. When ecosystems were mapped based on surface to seabed environmental data⁴, and biogeographic provinces based on the species observations⁵, we found that the RBA included all of them. Hence, the RBA is representative of the species, habitats, ecosystems and biogeography of European seas. The 10% most prioritised areas covered most coasts, offshore islands and edges of the continental shelf throughout the study area. This was expected as these areas collectively contain most species. The methodology follows best practice in systematic

conservation planning, recently reviewed by the Horizon Europe MarinePlan project⁶.

International cooperation outside Europe, including researchers in India and China, supported the prioritisation. We prioritised where to optimally protect finfish and shellfish species of fishery importance in European seas⁷. We found similar areas to the all-species prioritisation using two different source datasets (i.e., Food and Agriculture Organization (FAO) and the Sea Around Us Project (SAUP)), with negligible difference if using either species presence or species weighted by their biomass. A prioritisation of the West Pacific region found ~30% and ~60% of species could be protected in 10% and 30% of that area respectively⁸, and that simple metrics for species richness did not correlate with ecosystems and should thus not be used for prioritising areas for conservation⁹. We showed that there were coastal and High Seas areas in common across all six past global marine prioritisation studies even though these studies used different data and methods, yet they have not been recognised or utilised at global or regional scales¹⁰. Also, at a global scale and using expert derived (instead of modelled) species range maps, we showed that 51%, 75%, and 100% of marine species could be protected in 10%, 30%, and 50% of the global ocean respectively¹¹. The consistencies in all these studies, and our use of different sub-samples of the species for prioritisation^{2, 3}, indicates the results are robust, such that additional data and models will not alter

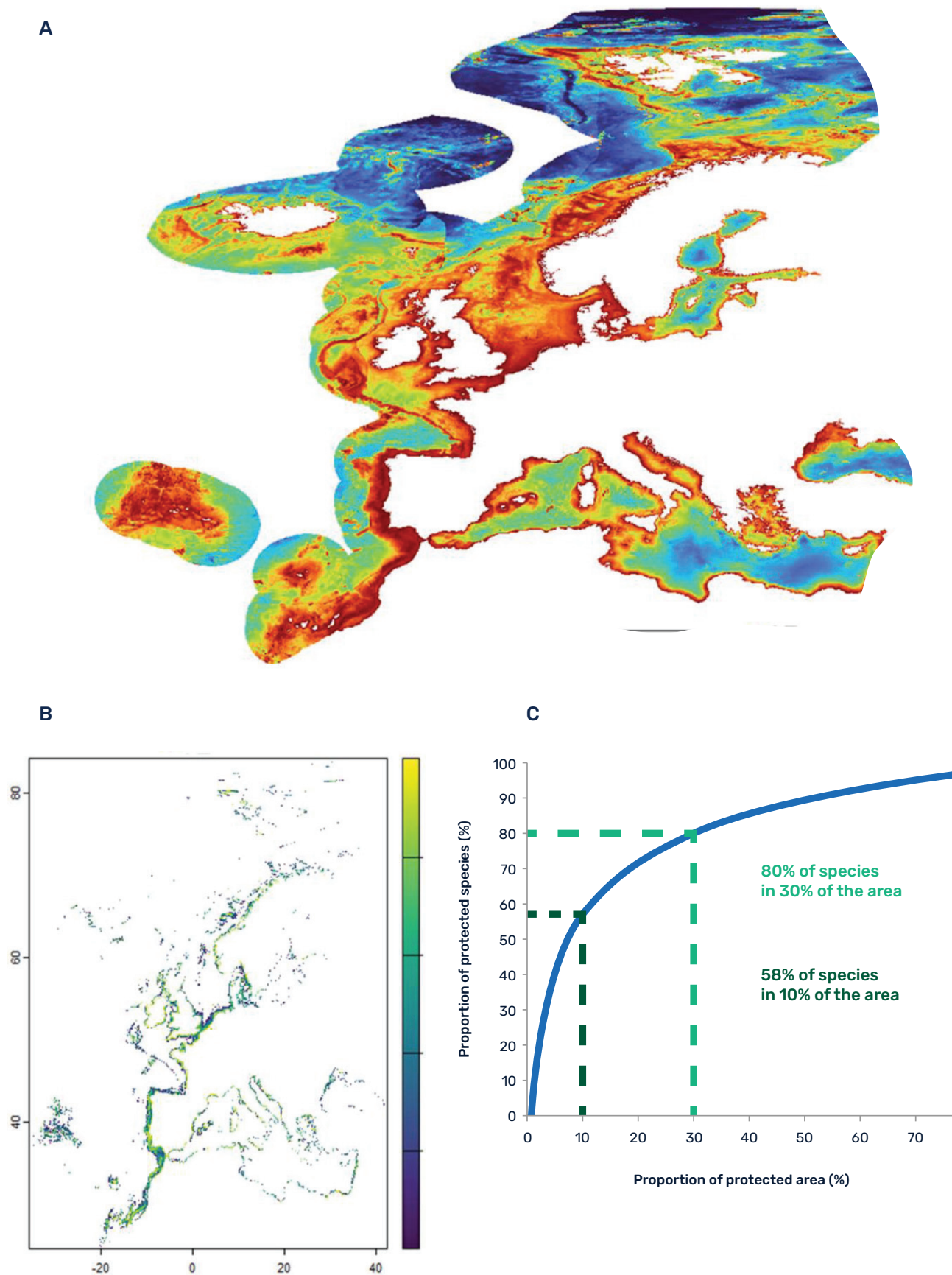


Figure 1. The prioritisation of Representative Biodiversity Areas (RBA) in all European seas (red is more, dark blue is less) (A) and the top 10% of the areas (B). The graph (C) shows the proportion of species that can be included in the proportion of the area if the optimal places are protected. Data from².

the overall geographic prioritisation. However, species highly threatened with extinction would still require species-specific conservation measures, such as interventions to protect feeding, spawning and nesting sites^{10, 12, 13}.

We significantly **expanded available data** to support marine conservation and resource planning in Europe in three ways. First, the Ocean Biodiversity Information System (OBIS) was expanded to now include 67 million distribution records for ~30,000 species in European seas¹⁴. Second, the Bio-ORACLE platform was further developed to provide ~6,500 global spatial layers across 18 environmental variables, spanning the sea surface to the seabed, including climate change (CMIP6-based) projections for five climate change scenarios from 2050 to 2100¹⁵. These global environmental data layers are at 0.5 degrees spatial resolution, include long-term averages, maxima, minima, and range, for surface and near seabed depths, air and sea temperature, salinity, oxygen, pH, nitrate, phosphate, silicate, iron, chlorophyll, productivity, sea ice cover and thickness, current speed and direction, mixed layer depth, diffuse attenuation coefficient, photosynthetically active radiation, bathymetry, slope, topographic aspect and variation. Third, and for the first time, a wave exposure layer at European scale was published^{16, 17}, because it is

known to be a key variable in influencing coastal species distribution¹⁸. We also found it was the strongest predictor of seabed carbon content when prioritising at a pan-European scale (at sea basin scale, other drivers including riverine input can be more significant)¹⁹.

Together, the species occurrence and environmental data were used to map the geographic ranges of over 10,000 species, including human-introduced species (Figure 2)^{20, 21, 22}. These provided standardised data for the prioritisation analysis. All the data and distribution models are open access on *MPA Europe Map Platform* (<https://shiny.obis.org/distmaps>)²³.

Our **online atlas** for MSP on the *MPA Europe Map Platform*²⁴ incorporates open-source species distribution models (SDM), the species distribution data used in the SDM, selected environmental variables, the RBA and the seabed carbon map based upon our new EURO-CARBON database^{25, 26, 27} (Figure 3). These new data and maps provide multiple opportunities to support Regional Seas Conventions and Member States with delivery of plans and measures required under the Nature Restoration Regulation (NRR)²⁸, the EU Biodiversity Strategy for 2030 (BDS)³⁰, the Marine Strategy Framework Directive (MSFD)³¹, the Maritime Spatial Planning Directive (MSPD)

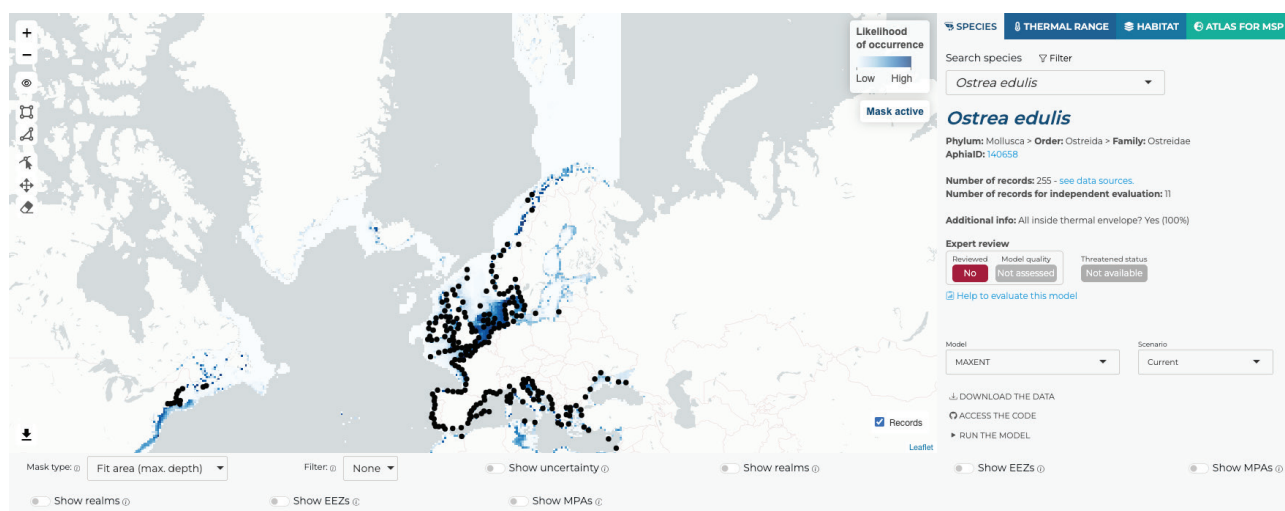


Figure 2.

Screenshot of the new atlas on the MPA Europe Map Platform of ~10,000 marine species (e.g., European oyster), including groups representing species that are habitat forming and of conservation interest. Multiple species distribution models are shown for present and future climate scenarios, and the observed data records. All source data and codes are open access <https://shiny.obis.org/distmaps/>.

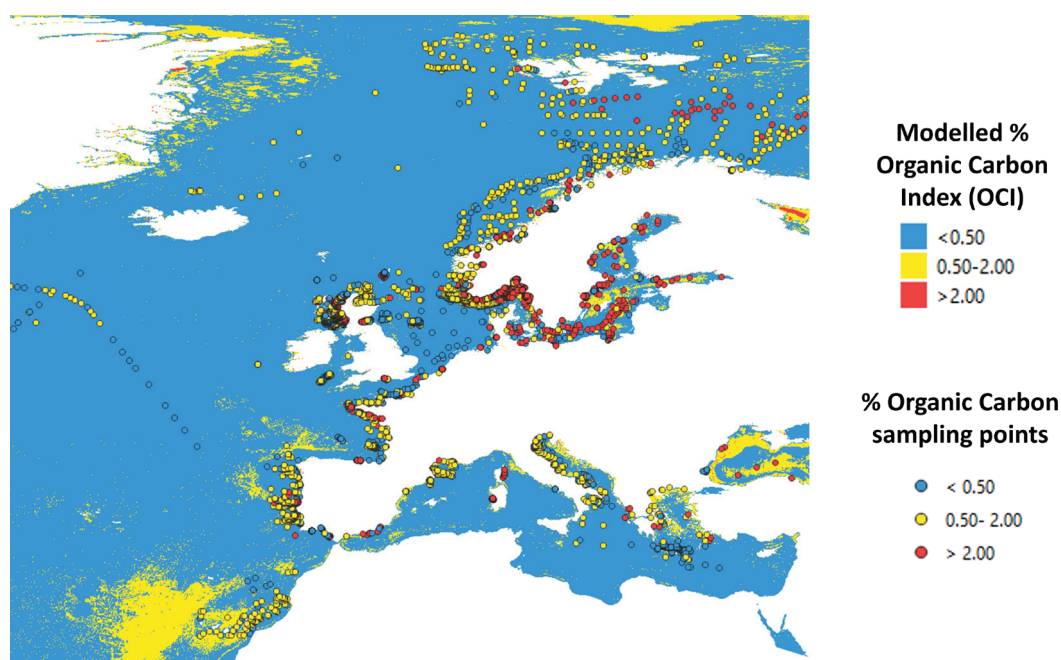


Figure 3. Map of the modelled (background) and source data records of organic carbon in the seabed. Highest concentrations are coastal, especially fjords and estuaries, and in Posidonia seagrass beds in the Mediterranean Sea. Data from⁴¹.

and the Birds and Habitats Directives (BHD)^{32, 33}. For example, the species range maps predict where a species may occur due to environmental suitability. Thus, if a species is not present is that due to lack of observations, human impacts, or loss of habitat. In this case, if the cause of its absence is addressed then the species should return if the habitat is restored. The RBA can be used to guide prioritisation of areas for nature conservation efforts because if the highest priority cells are chosen, then most species will recover in the RBA as the background environmental conditions are likely to be suitable for them. In addition, monitoring the most highly prioritised areas in the RBA would most cost-efficiently detect trends in marine biodiversity at a European and national scales. Thus, the RBA provides marine and maritime spatial planning (MSP) with data-driven knowledge for managing human activities to minimise loss of biodiversity. With increased focus on biodiversity-inclusive and climate-smart MSP, the systematic conservation planning analyses can be repeated using additional data that may become available and to take account of areas protected or restored. Such measures may be strict MPA,

Other Effective area-based Conservation Measures (OECM), similarly long-term (decadal) regulations protecting fisheries, and/or designation of areas for activities with limited impact on biodiversity if suitably located and managed appropriately (e.g., ecotourism, cable zones). The seabed carbon map identifies areas of higher organic carbon content in seabed sediments, and the atlas shows the potential range of habitat forming species. Together these layers can be used in MSP to preferably locate human activities which may disturb the seabed (e.g., anchoring, dredging, mobile bottom-contact fishing) outside of such areas.

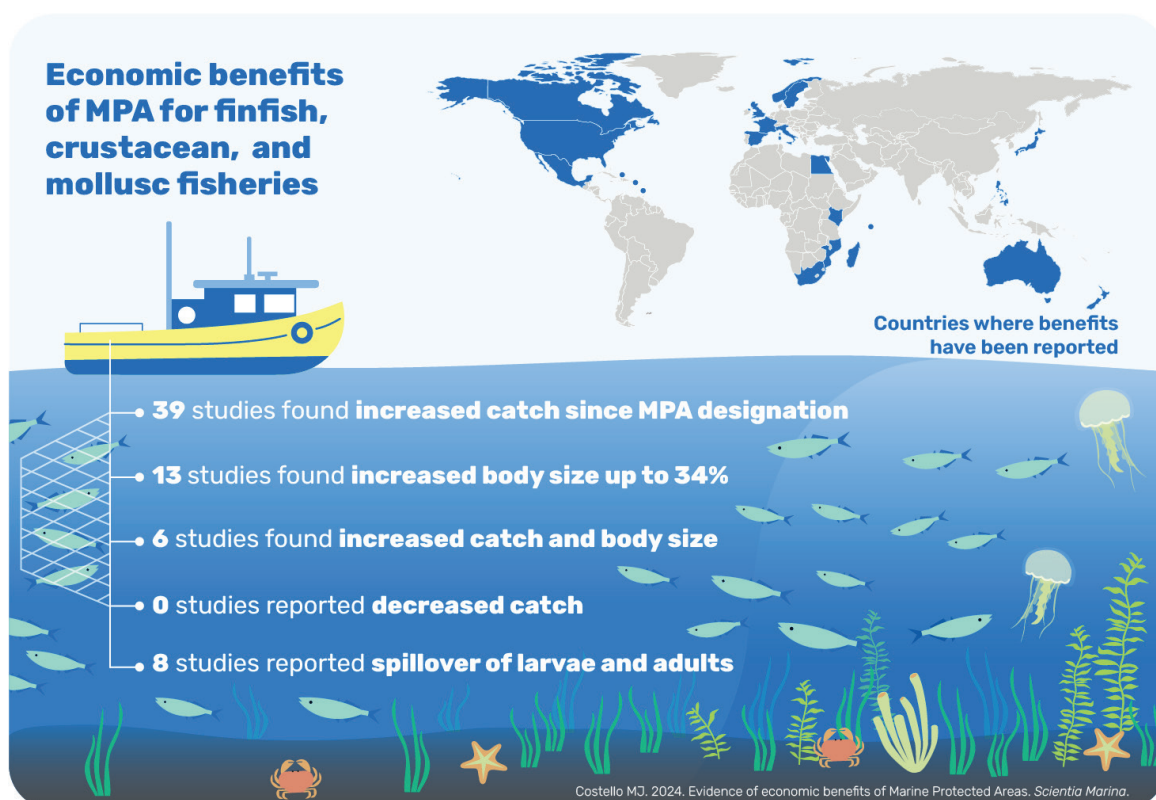
In spite of the fact that most of the public are in favour of MPA³⁴, problems persistent in implementing MPA for several reasons, including the existence of conflicting views of the socioeconomic and ecological costs and benefits of MPA, and MPA not being seen as political priorities³⁵. To address such questions from stakeholders, we reviewed the scientific literature and polled thousands of MPA experts for evidence of fishery losses due to MPA. We found 48 examples of fishery benefits and no examples of

any fishery losing catch due to no-fishing MPA or displacement effects of MPA on fisheries^{36, 37} (Figure 4). Rather, benefits to fisheries were reported from 25 countries in relation to finfish and shellfish species. These findings were also presented to the Portuguese parliament to support their designation of MPA, including strict (no-fishing) MPA, in the Azores. In addition, we found benefits of MPA in terms of tourism revenue and job creation (Figure 4).

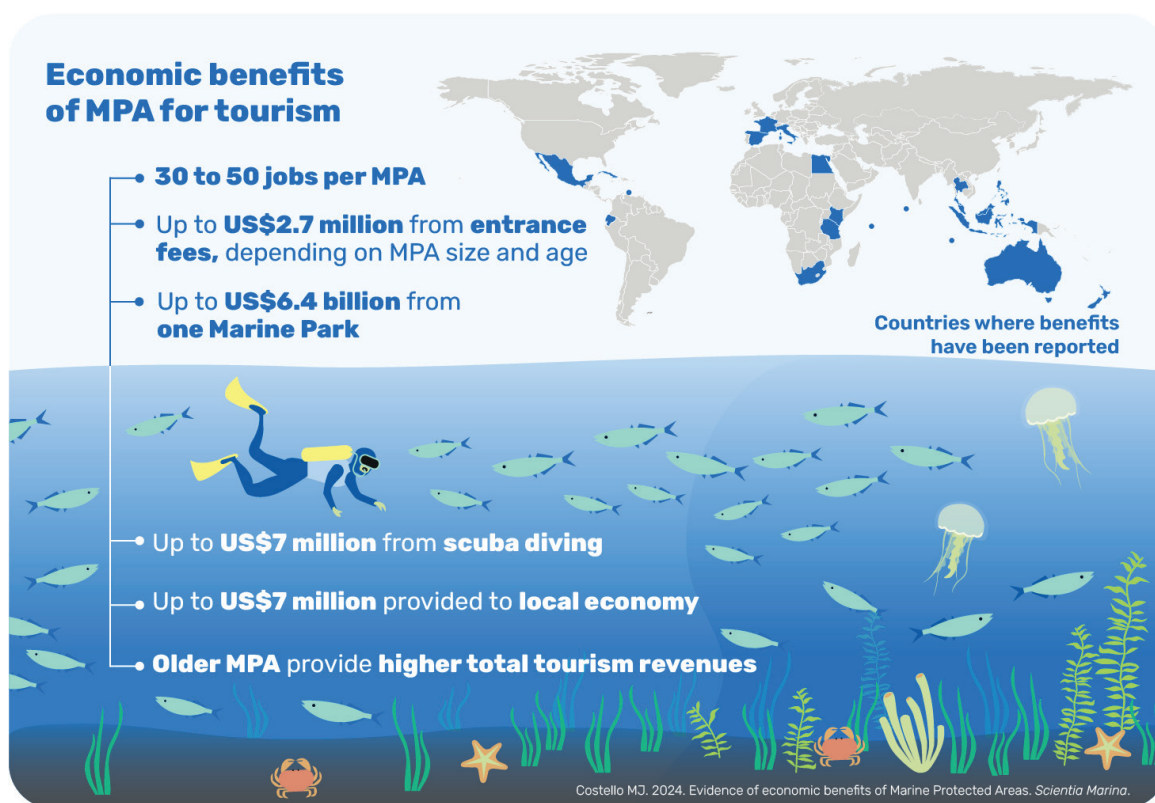
We assessed **how well marine species ranges overlapped the present MPA sites in Europe** using the world standard “MPA Guide”³⁸. This guide indicates how effectively MPA may be expected to protect biodiversity based on which human activities are allowed in the sites. We found most areas which may be consider as MPA (largely Natura 2000 sites) would not deliver effective conservation outcomes because they permit human activities that are incompatible with conservation. Thus, increased protection from human pressures in line with international standards should be a priority throughout the region^{39, 40}.

Climate resilience and adaptation options were considered with regard to projected species distributions under climate change scenarios^{20, 21}, and the distribution of carbon stores in seabed sediments based on sampled organic carbon content^{25, 41}. We found that the marine species projected distributions under the most extreme climate change scenarios by 2100 were encompassed in the RBA^{2, 3}. Thus, the RBA were predicted to be a climate change resilient network. Using the newly established EuroCarbon database, we mapped organic carbon content and identified the main predictors and patterns of sediment organic carbon across regional seas at a European scale^{20, 21, 41}. Human activities that release organic carbon from the seabed and potentially enhance degradation of these pools, such as trawling and dredging, could be prohibited in the areas with highest carbon stores^{42, 43}. Prohibiting these habitat destructive practices would also benefit biodiversity in those areas. However, generally, we found that the most highly prioritised areas in the RBA were not in the same places as the highest carbon content^{1, 2, 3}. Thus, MSP needs to consider restoring and protecting biodiversity, and safeguarding carbon stores in the seabed, separately.

A



B



C

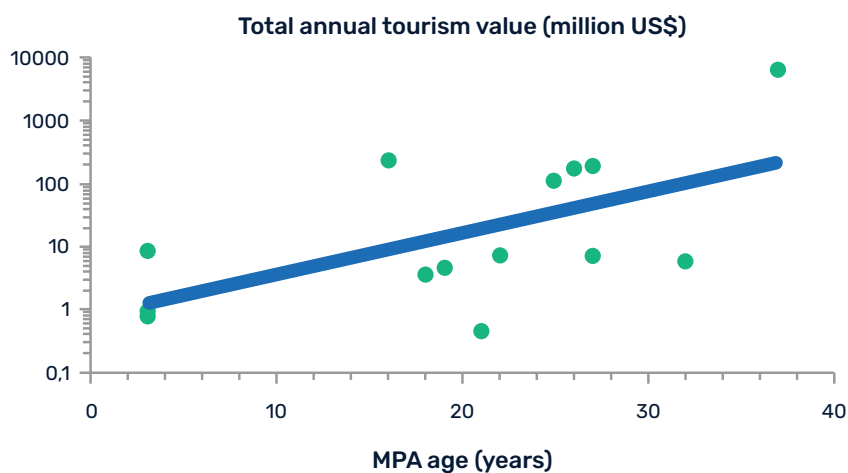


Figure 4. The economic benefits of MPA apply to (A) fisheries around the world; 91% of MPA benefiting fisheries were fully protected with no-fishing. (B) Tourism can also benefit with (C) increasing revenue with MPA age. No examples of a decline in fishery due to MPA were found. This is not surprising and can be considered a general rule. Data from³⁶.

Stakeholder engagement and feedback

We have engaged extensively from the outset of our project with almost 180 organisations⁴⁴ representing regional and national stakeholders in the Baltic, Black and Mediterranean Seas and North-East Atlantic Ocean, to share the knowledge of the project and seek stakeholder feedback. These included Regional Seas Conventions, Member States, national institutes, cross-sector organisations, regional fisheries advisory groups, blue economy actors and NGOs. Through over 30 workshops and events, we have sought to inform stakeholders about *MPA Europe's* approaches, tools and results; we invited stakeholders to provide feedback on these and experts to validate the SDM^{14, 45}; and to propose case studies which use *MPA Europe's* methods, tools or results. Discussions with stakeholders are captured in our four Regional Seas workshop reports^{46, 47, 48, 49}. Stakeholder “frequently asked questions” are on the *MPA Europe* website (<https://mpa-europe.eu/faqs/>) and have informed our recommendations here.

We worked closely with the Horizon Europe and EMFAF projects MSP4BIO, Marine Plan, PROTECT BALTIC, MSP Green and MEDIGREEN, including through joint stakeholder workshops, and contributed to a joint Think Tank coordinated by the MSP4BIO project which led to a joint Policy Brief⁵⁰. We contributed to recent MSP Global international guidelines on MSP for the Biodiversity Inclusive Principle⁵¹ and Climate-smart Principle⁵², and to IUCN guidance for establishing MPA in a changing climate⁵³. Therefore, **our policy recommendations build on the scientific results and reflect questions from stakeholders.**

Lack of MPA network coherence

Our work confirmed previous findings that the current network of MPA in Europe lacks coherence; it is not representative of all biodiversity. This has arisen because the Birds and Habitats Directives, which underpin most of the current MPA designations via the Natura 2000

network, do not adequately represent marine ecosystems and species⁵⁴. Because the Nature Restoration Regulation defines a fuller range of marine habitats and has a strict timetable, it should advance more coherent protection as well as restoration. In most marine habitats, passive restoration, that is, removing deleterious impacts, is the only practical approach to restoration. At the same time the MSFD explicitly requires the creation of coherent and representative networks of MPA. According to Article 13(4) of the Directive, the Member States must use spatial protection measures to contribute to the directive's primary goal to achieve or maintain Good Environmental Status (GES) for all EU marine waters by applying an ecosystem-based approach to management.

New MPA may be sited sub-optimally within national MSP processes. For example, stakeholders reported that Denmark's MSP process set aside 30% of its sea for renewable energy before finding 30% of the sea for marine protection, so new MPAs were designated in residual sites⁴⁸. These places have the lowest political cost and are not necessarily the areas that have the highest potential to recover or support the highest biodiversity⁴⁸. Continuing this trend of protecting biodiversity piecemeal from a national perspective and without prioritising important biodiversity areas nationally within MSP may result in European MPA networks which continue to lack coherence, and which are inefficient in the use of marine space within MSP processes⁵⁵. MSP needs to apply the precautionary principle while considering where existing and new human activities can minimise further loss of biodiversity. The RBA indicates where protection of biodiversity should be strengthened to provide an optimal return on MSP investment.



Unprotected MPA

The contemporary Horizon Europe MARHAB project found that protection in Europe's MPA is a magnitude lower than protected area coverage, with only 0.2% of EU MPA effectively protected and over 80% not qualifying as MPA because they permit human activities that are incompatible with effective marine conservation⁵⁶. We extended these data to include the UK³⁹ and are preparing a European scale assessment of how well the present "MPA" could protect species based on the *MPA Europe* data⁴⁰.

Stakeholders recommended that *MPA Europe*'s results should be used to improve and update protected area management plans⁴⁶. They noted that some interests such as fisheries organisations have different ambitions or expectations for MPA, and MPA range from fully to partially protected, so stakeholders need to agree conservation objectives (including for fisheries as relevant), appropriate management measures and the outcomes they expect from an MPA, taking these discussions forward within MSP processes⁴⁸.

Most MPA in Europe permit mobile bottom contact fishing gear. EU citizens and NGOs see a contradiction between protection in theory and protection in practice (the "paper parks" phenomenon) and are concerned about the lack of implementation plans to exclude certain fishing practices (such as bottom trawling) in MPA. Management of the seabed could ban disturbance of sediments with high organic carbon to prevent degradation of these stores and potential release of greenhouse gases such as carbon dioxide⁴².

Climate change and connectivity

Our stakeholder engagement work identified a misconception among stakeholders that MPA may need to move in response to species range shifts influenced by climate change (<https://mpa-europe.eu/faqs>). Marine planners are unclear about the impacts of climate change on species and lack relevant knowledge⁵⁷. Considering the

years it takes to establish MPA, and the nature of spatial planning and subsequent regulatory relationships with human activities, it is impractical to move MPA. It can take decades for biodiversity to recover in an MPA⁵⁸, so to move it could mean a reversal of restoration achieved. However, in the context of climate change, species are only likely to change their geographic distribution when temperatures exceed their tolerances in their present range (such as in lower latitudes or due to local heatwaves), and/or previously unsuitable areas become more suitable (such as warming in higher latitudes).

Comparisons of species' geographic ranges now and under projected climate change conditions in the *MPA Europe* atlas (Figure 2) show that many species ranges will change negligibly, while some will extend their distribution into Arctic waters⁵⁹ and others contract their range in southern European seas. Thus, most species will still occupy most of their present range under climate change this century. At local scales, species abundance is not only a reflection of oceanic climate, but ecological interactions and physical habitat conditions; including salinity, productivity, seabed substrata, wave and current exposure, and topographic heterogeneity. Because the distribution of these physical variables will not change significantly under climate change, areas that are suitable for species now, and/or may contain more species, will still be important for biodiversity under climate change.

It is fortunate that the RBA is climate resilient for marine species². MPA build climate resilience through restoring habitats and populations to abundance and acting as refugia for genetic diversity^{60, 61, 62} and they support ecological and social adaptation to climate change via multiple pathways⁶³. Moreover, emerging evidence indicates shading by macroalgae reduces the impacts of heatwaves on seabed life⁶⁴, and inclusion of deep waters may provide thermal refugia for fish and reduced exposure to heatwaves⁶⁶.

Marine species generally fill their environmental niche within their native range, indicating that



their distribution is more limited by their physiology and environmental suitability rather than their dispersal ability^{67, 68, 69, 70}. The only hard barriers to their movement are land, as evident from the ranges of species filling their environmental niche (geographic) space as shown on the *MPA Europe* atlas. Thus, connectivity is most important where a species needs to extend its range to adapt to climate change. The present distribution of species in the near absence of MPA shows that MPA are not necessary for species' connectivity. Observations of marine species moving their distribution at global scales in concert with ocean warming⁷¹ including a doubling of fish species in the Barents Sea since the 1980s⁵⁹, show that connectivity is not limiting fish species' expansion under climate change. Exceptions to these general trends may be species endemic to the Mediterranean and Macaronesian islands, particularly if they are exposed to extreme heat waves^{72, 73}. Because most species already have wide ranges extending beyond existing MPA and RBA, connectivity is not a general problem for marine nature conservation⁷⁴, assuming seabed trawling and pollution are not so severe as to have formed barriers to species dispersal. However, some large mammals, birds, turtles and fish species with low abundance, may need protection from accidental mortality (e.g., in fishing gear, ship-strikes) during their seasonal migrations which is another form of connectivity⁷⁵. The application of MSP, using the RBA, is complementary to measures needed to protect species which may need protection throughout their range. Furthermore, local scale data on particular areas important for spawning, breeding, nesting, feeding, and as nurseries, would add value to the wider geographic context provided by the RBA.

Terminology and awareness

Stakeholders also sought clarity on terminology related to ecosystems and habitats classifications, including biogenic habitats⁴⁶. Arising from such questions, EMODnet Habitats (a partner in *MPA Europe*) has now labelled such habitats, formed by particular habitat forming species, as such in

its platform. There remains varying use and misuse of terminology regarding the concepts of habitats, ecosystems and biomes, especially in marine sciences, which should be streamlined with the definitions in terrestrial ecology⁷⁶.

Our stakeholders identified a need to raise awareness and educate the business sector and civil society on MPA networks, since the need for urgent biodiversity protection is not as widely understood as the need to address climate change. Indeed, protection of biodiversity is a prerequisite for climate change adaptation, particularly to reverse the losses to biodiversity from past and continuing existing human activities^{60, 77, 78, 79}. Some stakeholders also noted environmental protection is lacking in national MSP processes⁴⁷.

Ocean P(A)ct and MSP

Our work showed MPA should be framed as an engine for a sustainable blue economy, not an obstacle to it, while acknowledging there is a time lag for the recovery of biodiversity before ecological and economic benefits are realised⁸⁰. The European Ocean Pact⁸¹ adopted in June 2025, is a **comprehensive strategy** to better protect the ocean, promote a thriving blue economy and support the well-being of people living in coastal areas. Its first priority refers to "protecting and restoring ocean health", with main areas of action to support Member States to restore degraded coastal and marine habitats. The European Ocean Pact proposes to evaluate and revise the **Maritime Spatial Planning Directive**; encourage Member States to establish and manage **marine protected areas**; and create European **blue carbon reserves**.

The upcoming European Ocean Act will build on a revision of the MSP Directive and aim at strengthening and modernising MSP as a strategic tool that will serve the priorities of the Ocean Pact and their implementation. It seeks to improve the coherence of maritime policies, streamline reporting, and create a single point of reference for

economic, environmental, and social targets, revising Directive 2014/89 on MSP to better manage marine waters, and to strengthen and modernise MSP as a strategic tool that serves and implements the European Ocean Pact's priorities. It seeks to do this through increased cross-sectoral coordination at national level and a better organised sea-basin approach. It also aims to improve ocean observation governance. Therefore, MSP is becoming a more important tool and MSP processes are a route to sharing accurate, best available evidence on MPA experiences, to dispel myths and address stakeholder concerns about the impacts of MPA. We heard from stakeholders that the Common Fisheries Policy creates a challenge to Member States establishing MPA outside their territorial waters, because they find the process is too complicated⁴⁸. It may also result in weaker final restrictions than proposed by the Member State⁸².

At the same time, fisheries are facing “spatial squeeze” resulting in reduced or more distant

fishing opportunities, as offshore energy and other maritime sectors expand, alongside new MPA designations⁴⁸. More inclusive and participatory MSP processes targeting fisheries groups and economic support for a just transition for fishing communities can be used in tandem to facilitate more constructive engagement on MPA, as demonstrated recently in the Azores⁸³.

The EC and Member States can use *MPA Europe's* educational and scientific resources for MSP processes and stakeholder communication campaigns on the benefits of MPA networks (e.g., for ocean literacy). These include our videos, presentations, and infographics accessible on the *MPA Europe* website⁸⁴. Regional Seas Conventions and Member States can use *MPA Europe's* Map Platform in conjunction with national data for developing evaluations of ecosystem services, and contributing to the adoption of a natural capital approach to MSP decision-making.



Policy recommendations

Recalling that “the BDS, BHDs, NRR, and the renewed view of MSFD spatial protection call for a coherent and representative network of protected areas to halt biodiversity loss and to increase the resilience of the marine environment, particularly vis-à-vis climate change”⁸⁵, we recommend that Regional Seas Conventions and Member States use and build on *MPA Europe*’s atlas and data layers for planning future MPA networks in Europe’s seas. Furthermore, Regional Seas Conventions and Member States should enhance the *MPA Europe*’s Map Platform by including regional and national data into OBIS, including for example species abundance data. Additional information for areas of conservation importance, such as Key Biodiversity Areas, which include Important Marine Mammal Areas, Important Bird Areas, Important Shark and Ray Areas, and fish nursery areas can also be added to OBIS, or maps of these areas can be overlaid with the atlas, to further inform optimal areas for protection. The results can also be placed into a wider spatial context, including the High Seas and global ocean by examination of our published papers^{7, 8, 9, 10, 12, 13}.

1. The 10% and 30% Representative Biodiversity Areas should be prioritised

for increasing protection and restoring habitats, through expanding existing MPA, establishing new MPA, recognising OECM and other regulatory measures, to achieve the 2030 targets as part of climate smart Marine and Maritime Spatial Planning (MSP) to implement the Nature Restoration Regulation, Bird and Habitat Directives, Marine Strategy Framework Directive, Maritime Spatial Planning Directive, and EU Biodiversity Strategy.

2. Prioritise action on strictly protected MPA

as strict protection is most effective for ecological restoration and fishery benefits and applies both the precautionary principle and whole ecosystem-based approach to environmental management.

3. Determine new MPA designations with local communities and stakeholders

including MPA boundaries and management informed by local knowledge of species and habitat distributions, and human values; coordinated by local and national government, to ensure social equity and compliance with regulations.

4. Member States and regional seas convention organisations should apply SMARTIE goals

(specific, measurable, attainable, relevant, time-bound, inclusive and equitable) for marine biodiversity protection and MSP.

5. Enable Regional Seas Conventions to lead MPA planning to optimise effective conservation

through transboundary MSP to harmonise sensitivity mapping, ecological objectives and sectoral constraints across borders, so that national plans collectively deliver a coherent basin-scale conservation network.



6. MPA planning, aims, management and reporting, would be clarified and simplified by international standards

such as the IUCN Categories for protected areas and the “MPA Guide”.

7. Prohibit human activities that damage habitats in MPA

to preserve site integrity.

8. Prohibit human activities that disturb seabed areas with high carbon stores

as a precautionary approach to minimise carbon emissions is warranted pending greater scientific understanding.

9. Provide regular training and communications materials to Member states on effective MPA management

practices and climate change effects on marine species and ecosystems, to inform marine protection and restoration, and adaptive climate-smart MSP.

10. The European Commission and Member States should mandate that national species distribution, abundance and associated environmental and sampling data are published

into the international standardised data systems that integrate data to enable ease of data access, reproducibility and reusability; such as EMODnet, OBIS, and GBIF.



References, with MPA Europe publications in blue

- ¹ Addamo, A.M., et al. 2025. Prioritisation analysis based on biodiversity variables and blue carbon. Nord University, MPA Europe Project Report Deliverable 5.5. <https://doi.org/10.5281/zenodo.16158038>.
- ² Addamo, A.M., et al. A systematically designed network of representative and climate resilient areas for the protection of marine biodiversity in European seas. *In submission*
- ³ Addamo, A.M., et al. 2025. Paper on the MPA networks in European Seas based on the prioritisation analysis for biodiversity conservation and blue carbon. Nord University, MPA Europe Project Report Deliverable 5.6.
- ⁴ Campoy, A.N., Assis, J. & Costello, M.J. 2024. Paper on the marine ecosystem classification for surface and near seabed waters in Europe. MPA Europe Project Report Deliverable 2.6. <https://doi.org/10.5281/zenodo.17590666>.
- ⁵ Gordó-Vilaseca C., et al. 2025. Marine Bioregions of European Seas. MPA Europe, unpublished report.
- ⁶ Giakoumi, S., et al., 2025. Advances in systematic conservation planning to meet global biodiversity goals. *Trends in Ecology & Evolution* 40(4), 395–410.
- ⁷ Abinaya, R., et al. 2026. Identifying priority areas for marine protection in Europe to support fisheries. *npj Ocean Sustainability* 5, 6.
- ⁸ Zhao, Q., Huang, H. & Costello, M.J. 2024. Systematic planning shows more than half of the most species-rich ocean region is needed to include all species in representative protected areas. *Global Ecology and Conservation* 53, e03036.
- ⁹ Zhao, Q., Huang, H. & Costello, M.J. 2025. No clear relationships between environmentally classified ecosystems and species diversity. *Marine Ecology Progress Series* 764, 1–14.
- ¹⁰ Zhao, Q. & Costello, M.J. 2025. Marine Protected Area planning can think globally and act locally. *Trends in Ecology and Evolution* 40 (8), 772–781.
- ¹¹ Zhao, Q. & Costello, M.J. 2025. How to protect biodiversity when the 30% by 2030 target can only include up to two-thirds of all species. *Ecography*, e08130.
- ¹² Zhao, Q., et al. 2020. Where Marine Protected Areas would best represent 30% of ocean biodiversity. *Biological Conservation* 244, 108536.
- ¹³ Jefferson T., et al. 2021. Conserving threatened marine species and biodiversity requires 40% ocean protection. *Biological Conservation* 264, 109368.
- ¹⁴ Principe, S., et al. 2023. Compile additional data and publish it into OBIS. MPA Europe Project Report Deliverable 3.1. <https://doi.org/10.5281/zenodo.8096273>.
- ¹⁵ Assis, J., et al. 2024. Bio-ORACLE v3.0. Pushing marine data layers to the CMIP6 Earth System Models of climate change research. *Global Ecology and Biogeography* 33(4), e13813.
- ¹⁶ Burrows, M.T., et al. 2023. Paper on wave exposure index for all European coasts. MPA Europe Project Report Deliverable 2.2. <https://doi.org/10.5281/zenodo.17590383>
- ¹⁷ Burrows, M. 2020. Wave fetch GIS layers for Europe at 100m scale. A Dataset. <https://doi.org/10.6084/m9.figshare.8668127>
- ¹⁸ Burrows, M.T. 2012. Influences of wave fetch, tidal flow and ocean colour on subtidal rocky communities. *Marine Ecology Progress Series*, 445:193–207
- ¹⁹ Burrows, M.T., Assis, J. & Principe, S.C. 2025. Climate velocity map for European seas under recent conditions. MPA Europe Project Report Deliverable 2.8. <https://doi.org/10.5281/zenodo.14659560>.
- ²⁰ Principe, S.C., et al. Mapping marine species distributions to inform the design of protected areas in Europe. *submitted*
- ²¹ Principe, S.C., et al. 2023. Publish maps and models of species environmental niches and geographic distributions in Europe on OBIS. Nord University, MPA Europe Project Report Deliverable 3.2. <https://doi.org/10.5281/zenodo.17580071> (+ Appendix <https://doi.org/10.5281/zenodo.10058739>).
- ²² Principe, S., et al. 2024. Database of species and habitats conservation status. MPA Europe Project Report Deliverable 3.4. <https://doi.org/10.5281/zenodo.11075390>
- ²³ Ocean Biodiversity Information System (OBIS). 2024. Species distribution dashboard for MPA Europe. (version 0.1.0). <https://shiny.obis.org/distmaps>. <https://doi.org/10.5281/zenodo.14524781>.
- ²⁴ Addamo, A.M., et al. 2025. The MPA Europe online atlas for marine spatial planning. MPA Europe Project Report Deliverable 5.7. <https://doi.org/10.5281/zenodo.17610687>.
- ²⁵ Lønborg, C., et al. Major drivers and patterns of sediment organic carbon in European regional seas. *submitted*



- ²⁶ Graversen, A.E.L., et al. 2025. A marine and salt marsh sediment organic carbon database for European regional seas (EURO-CARBON). Data in Brief 60, 111595.
- ²⁷ Lønborg, C., et al. 2025. EURO-Carbon Full Dataset. <https://doi.org/10.5281/zenodo.17512391>
- ²⁸ Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869 (Text with EEA relevance). 2024. OJ L 2024/1991, 29.7.2024.
- ²⁹ European Commission: Directorate-General for Environment. 2021. EU biodiversity strategy for 2030 – Bringing nature back into our lives, Publications Office of the European Union. <https://data.europa.eu/doi/10.2779/677548>.
- ³⁰ Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). 2008. OJ L 164/19. 25.6.2008.
- ³¹ Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning. 2014. OJ L 257/135. 20.8.2014.
- ³² Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. 1992. OJ L 206, 22/07/1992 P. 0007 – 0050.
- ³³ Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (codified version). 2010. OJ L 020 26.1.2010, pp. 7.
- ³⁴ Michaelsen, P., Sundström, A., Jagers, S.C. 2025. Mass support for conserving 30% of the Earth by 2030: Experimental evidence from five continents. *Proceedings of the National Academy of Sciences* 122(35), e2503355122.
- ³⁵ OSPAR 2024. OSPAR Report on potential solutions to overcoming barriers to effective management of Marine Protected Areas, Publication Number: 1054/2024.
- ³⁶ Costello, M.J. 2024. Evidence of economic benefits of MPA to fisheries and tourism. *Scientia Marina* 88 (1), e080.
- ³⁷ Costello, M.J. 2024. Fully-protected Marine Protected Areas do not displace fisheries. *Proceedings of the National Academy of Sciences* 121 (34), e2412543121.
- ³⁸ Grorud-Colvert, K., et al. 2021. The MPA Guide: A framework to achieve global goals for the ocean. *Science*, 373(6560), eabf0861.
- ³⁹ Sim, E. 2025. Regulations of Human Activities & Protection Levels in Marine Protected Areas of the United Kingdom. Figshare. Dataset. <https://doi.org/10.6084/m9.figshare.29901479.v5>.
- ⁴⁰ Eskuche-Keith, P., et al. Stronger protection of Marine Protected Areas is needed to ensure the effective safeguarding of European marine biodiversity. In preparation
- ⁴¹ Addamo, A.M., et al. 2024. Map of carbon storage capacity for European for marine habitats. MPA Europe Project Report Deliverable 4.5. <https://doi.org/10.5281/zenodo.17591750>.
- ⁴² Porz L., et al. 2024. Quantification and mitigation of bottom-trawling impacts on sedimentary organic carbon stocks in the North Sea. *Biogeosciences* 21, 2547-2570
- ⁴³ Zhang, W., et al. 2024. Long-term carbon storage in shelf sea sediments reduced by intensive bottom trawling. *Nature Geoscience* 17(12), 1268-1276.
- ⁴⁴ Bramley, B., et al. 2024. Four regional case studies synthesising stakeholder views identified and outlined, meeting end user needs. Nord University, MPA Europe Project Report Deliverable 6.2. <https://doi.org/10.5281/zenodo.15311533>
- ⁴⁵ Principe, S.C., et al. A tool for web-based expert evaluation of species distribution models. In preparation
- ⁴⁶ Bramley, B., et al. 2024. Baltic Sea stakeholder workshop. 29th February, 2024. <https://zenodo.org/records/10974715>
- ⁴⁷ Bramley, B., et al. 2024. Black Sea stakeholder workshop. 20th June, 2024. <https://zenodo.org/records/12749872>
- ⁴⁸ Bramley, B., et al. 2025. North-east Atlantic stakeholder workshop. 18th February, 2025. <https://zenodo.org/records/15026795>
- ⁴⁹ Bramley, B., et al. 2024. Mediterranean sea stakeholder workshop. 28th January, 2025. <https://zenodo.org/records/15026742>
- ⁵⁰ Stojanovic I., et al. 2025. MSP4BIO: improved science based maritime spatial planning to safeguard and restore biodiversity in a coherent european MPA network. Accessed at <https://msp4bio.eu/publications/> on 30 January 2026.

- ⁵¹ UNESCO–IOC and European Commission. 2025. MSPglobal International Guide on Marine/Maritime Spatial Planning: Volume 2 – Biodiversity Inclusive Principle. IOC Manuals and Guides No. 89, Volume 2, Paris, UNESCO.
- ⁵² UNESCO–IOC and European Commission. 2025. MSPglobal International Guide on Marine/Maritime Spatial Planning: Volume 3 – Climate-smart Principle. IOC Manuals and Guides No. 89, Volume 3, Paris, UNESCO.
- ⁵³ Wenzel, L., et al. 2025. Establishing Marine Protected Areas in a Changing Climate. IUCN WCPA Technical Report Series No. 9. IUCN; IUCN World Commission on Protected Areas.
- ⁵⁴ Reker, J., et al. 2015. Marine protected areas in Europe's seas. An overview and perspectives for the future. European Environment Agency, Publication Office of the European Union, Luxembourg, 1–35.
- ⁵⁵ Stephenson, F., et al. 2025. Quality of marine protected areas is critical to achieving global biodiversity targets. *npj Ocean Sustainability* 4(1), 63.
- ⁵⁶ Aminian-Biquet, J., et al. 2024. Over 80% of the European Union's marine protected area only marginally regulates human activities. *One Earth* 7(9), 1614–1629.
- ⁵⁷ Zaucha, J., et al. 2025. Implementing the EU MSP Directive: Current status and lessons learned in 22 EU Member States. *Marine Policy* 171, 106425.
- ⁵⁸ Leleu K, et al. 2012. Mapping habitat change after 30 years in a marine reserve shows how fishing can alter ecosystem structure. *Biological Conservation* 155, 193–201.
- ⁵⁹ Gordó-Vilaseca, C., et al. 2023. Three decades of increasing fish biodiversity across the north-east Atlantic and Arctic Oceans. *Proceedings of the National Academy of Sciences* 120(4), e2120869120.
- ⁶⁰ Costello, M.J. 2021. Biodiversity conservation through protected areas supports healthy ecosystems and resilience to climate change and other disturbances. In: *Reference Module in Earth Systems and Environmental Sciences*, Elsevier. <https://doi.org/10.1016/B978-0-12-821139-7.00164-1>.
- ⁶¹ Benedetti-Cecchi, L., et al. 2024. Marine protected areas promote stability of reef fish communities under climate warming. *Nature Communications* 15(1), 1822.
- ⁶² Ortiz-Villa, E.M., et al. 2025. Marine protected areas enhance climate resilience to severe marine heatwaves for kelp forests. *Journal of Applied Ecology*, 62(9), 2439–2453.
- ⁶³ Ocean and Climate Platform, 2022. The contribution of marine protected areas to climate change adaptation state of the evidence and policy recommendations. Available at https://ocean-climate.org/wp-content/uploads/2022/11/Policy-Brief_Adaptation_MPA.pdf on 30 January 2026.
- ⁶⁴ Kumagai, J.A., et al. 2024. Marine protected areas that preserve trophic cascades promote resilience of kelp forests to marine heatwaves. *Global Change Biology* 30(12), e17620.
- ⁶⁵ Burrows, M.T., et al. 2019. Ocean community warming responses explained by thermal affinities and temperature gradients. *Nature Climate Change* 9(12), 959–963.
- ⁶⁶ Sun, C., et al. 2024. Climate refugia in the Great Barrier Reef may endure into the future. *Science Advances*, 10(48), eado6884.
- ⁶⁷ Pinsky, M. L., et al. 2019. Greater vulnerability to warming of marine versus terrestrial ectotherms. *Nature* 569 (7754), 108–111.
- ⁶⁸ Deutsch, C., et al. 2015. Climate change tightens a metabolic constraint on marine habitats. *Science* 348(6239), 1132–1135.
- ⁶⁹ Deutsch, C., Penn, J.L., & Seibel, B., 2020. Metabolic trait diversity shapes marine biogeography. *Nature* 85(7826), 557–562.
- ⁷⁰ Endress, M.G.A., et al. 2024. Thermal optima in the hypoxia tolerance of marine ectotherms: Physiological causes and biogeographic consequences. *PLoS Biology* 22(1), e3002443.
- ⁷¹ Chaudhary, C., et al. 2021. Global warming is causing a pronounced dip in marine species richness at the equator. *Proceedings of the National Academy of Sciences* 118(15), e2015094118.
- ⁷² Garrabou, J., et al. 2022. Marine heatwaves drive recurrent mass mortalities in the Mediterranean Sea. *Global Change Biology* 28(19), 5708–5725.
- ⁷³ Konsta, K., et al. 2026. Increasing bottom marine heatwaves pose a critical risk to Mediterranean benthic species. *Cell Reports Sustainability* 3, 100610.
- ⁷⁴ Costello, M.J. & Connor, D.W. 2019. Connectivity is generally not important for marine reserve planning. *Trends in Ecology and Evolution* 34(8), 686–688.
- ⁷⁵ Sequeira, A.M., et al. 2025. Global tracking of marine megafauna space use reveals how to achieve conservation targets. *Science* 388(6751), 1086–1097.
- ⁷⁶ Costello, M.J., Zhao, Q. & Jayathilake, D.R.M. 2020. Defining marine spatial units: realms, biomes, ecosystems, seascapes, habitats, biotopes, communities and guilds. In: Goldstein, M.I., DellaSala, D.A. (Eds.), *Encyclopedia of the World's Biomes*, vol. 4. Elsevier, pp 547–555. <https://doi.org/10.1016/B978-0-12-409548-9.12515-1>.

- ⁷⁷ Costello, M.J. 2022. Restoring biodiversity and living with nature (based solutions). In: *Imperiled: The Encyclopedia of Conservation*, Elsevier, 7-14. <https://doi.org/10.1016/B978-0-12-821139-7.00233-6>.
- ⁷⁸ Costello, M.J., et al. 2022: Cross-Chapter Paper 1: Biodiversity Hotspots. In: *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [H.-O. Pörtner et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2123-2161.
- ⁷⁹ Nikolaou, A., Borja, A. & Katsanevakis, S. 2025. What Do We Know About the Environmental Status of European Seas? *Conservation Letters* 18(4), e13118.
- ⁸⁰ Franceschini, S., Lynham, J. & Madin, E.M. 2024. A global test of MPA spillover benefits to recreational fisheries. *Science Advances* 10(29), eado9783.
- ⁸¹ European Commission. 2025. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: The European Ocean Pact. COM(2025) 281 final, 5 June 2025.
- ⁸² European Court of Auditors, 2020. Marine environment: EU protection is wide but not deep. Available at https://www.eca.europa.eu/lists/ecadocuments/sr20_26/sr_marine_environment_en.pdf on 30 January 2026.
- ⁸³ Government of Azores communication, 2025. Available at <https://portal.azores.gov.pt/en/web/comunicacao/news-detail?id=17629456> on 30th January 2026.
- ⁸⁴ MPA Europe website. Infographics at <https://mpa-europe.eu/infographics> and Videos at <https://www.youtube.com/@mpaeuropeproject/videos>.
- ⁸⁵ European Commission 2020. Commission Staff Working Document. Report on the Implementation of the Marine Strategy Framework Directive (MSFD) and Assessment of the State of Marine Waters (SWD(2020) 61 final / COM(2020) 259). EUR-Lex. 2020.
- ⁸⁶ Day, J., et al. 2012. Guidelines for applying the IUCN protected area management categories to marine protected areas. IUCN.



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