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# Identifying priority areas for marine protection in Europe to support fisheries



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Balancing biodiversity conservation with fisheries sustainability is a challenge in marine spatial planning. We identified marine areas supporting commercially important fish species in European seas using spatial prioritisation. Species range maps from the Ocean Biodiversity Information System (OBIS) and fishery catch data from the Food and Agriculture Organization (FAO) and the Sea Around Us Project (SAUP) were combined including 507 finfish, 73 crustacean and 101 mollusc species, to represent both presence-only and catch biomass scenarios. Results were consistent across scenarios, with optimal areas concentrated along the Mediterranean, Black Sea, North-East Atlantic coasts, Macaronesia, Iceland, and continental shelves of the North, Celtic and Irish Seas. Over 80% of species could be protected in 30% of European seas, and 51% in 10% of the area. Conserving commercially fished species would benefit biodiversity and fisheries stock recovery, through refugia for broodstock and juveniles, larger fish and greater genetic diversity and spillover. Our findings support evidence-based marine spatial planning that can enhance sustainable fisheries management in European seas.

The North-East Atlantic (FAO Major Fishing Area 27) is a striking example of a long-term decline in fisheries. Total landings in the region were 13 million tonnes in 1976 but then declined steadily due to intense fishing pressure throughout the late 1970s and 1980s and were down to 7.9 million tonnes in 2021<sup>1</sup>. Recovery is not possible under the present management conditions due to overestimation of stock recovery, and harvest quota exceeding scientific advice<sup>2,3</sup>. This decline in fish landings has drawn attention to the essential need for better spatial planning to restore fish populations and maintain long-term viability<sup>4,5</sup>.

One of the global responses to the loss of marine biodiversity is the creation of Marine Protected Areas (MPAs) as a management strategy for fishery resources<sup>6–10</sup>. MPAs are a tool to support an Ecosystem Approach to Fisheries, which aims to balance ecological integrity with socioeconomic factors<sup>11</sup>. No-take MPAs, sometimes called marine reserves, fully, or strictly protected areas, can significantly contribute to conserving spawning biomass and supporting adjacent fisheries through larval dispersal and adult spillover<sup>12–16</sup>. However, the feasibility of MPAs in producing demonstrable fishery benefits depends heavily on where they are placed, relative to spatial alignment with fishing intensity and the distribution of target species<sup>7,17,18</sup>. Misalignment between MPA locations and ecologically or economically important areas limits their

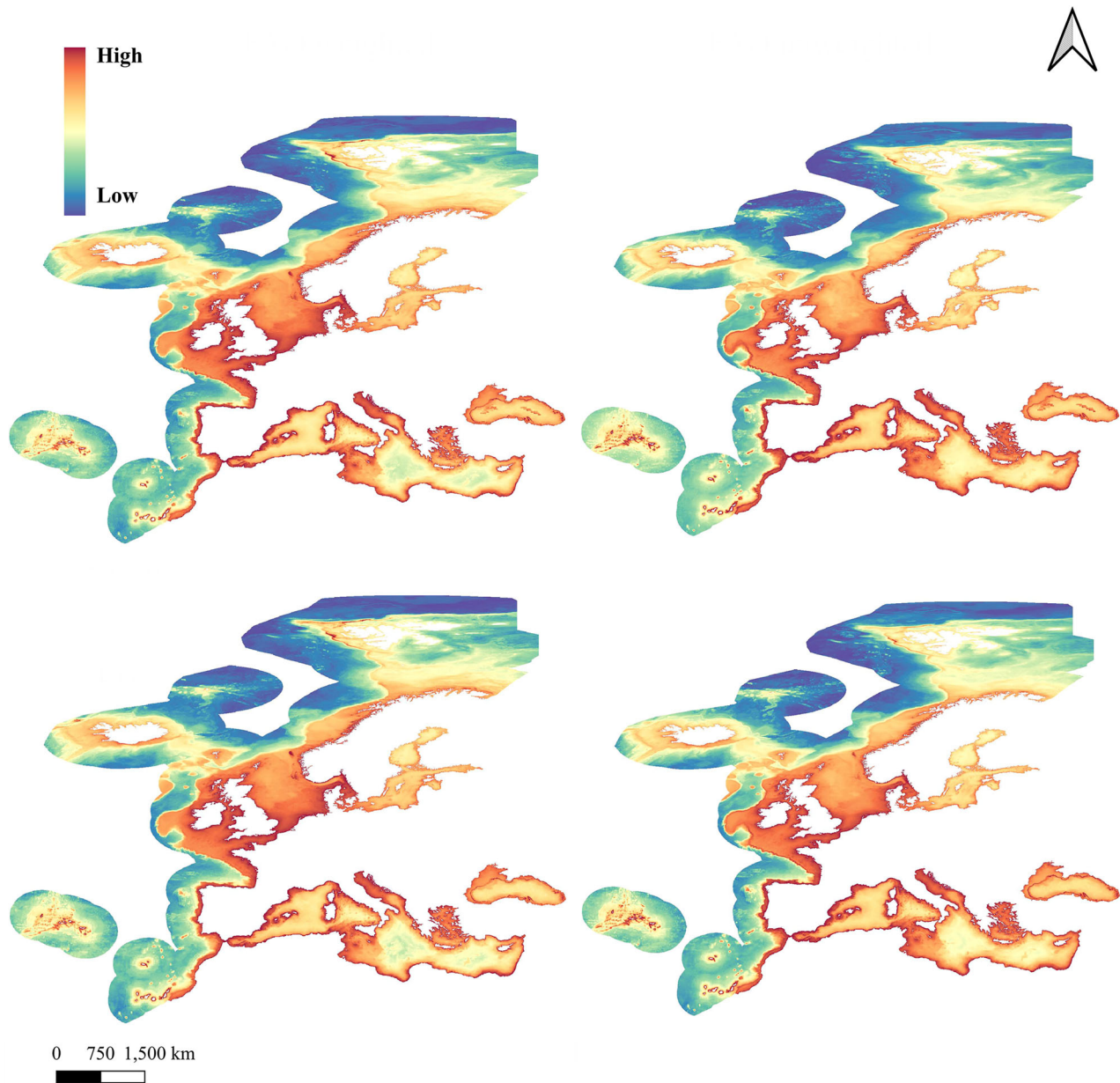
effectiveness, particularly for stakeholders who rely on adjacent fisheries<sup>16,19,20</sup>.

The European Union (EU) has marine conservation targets under the EU Biodiversity Strategy for 2030, committing to protecting at least 30% of the seas for nature by 2030, with one-third of these areas being strictly protected (i.e., 10% of European seas to be strictly protect)<sup>21–23</sup>. To date, most existing MPAs in Europe have been designated for the conservation of particular habitats and species, and not for fisheries benefits. An analysis of fishery species distributions could indicate where an MPA network could optimally protect fisheries.

Despite their ecological and economic benefits, as of 2024, only approximately 3% of the world ocean was fully and highly protected (2.7% by MPAtlas, 3.7% from fishing in Protected Seas Navigator<sup>24,25</sup>). Only 11% of EU seas are designated as MPA but only 0.2% is fully (no fishing) or highly protected from fishing<sup>26</sup>. Thus, there is almost nowhere in the EU where fishery species are protected from being fished. These findings point to the necessity of establishing fully protected MPAs which have been shown to improve fishery outcomes and ecological integrity without any negative effects on fisheries or fishery displacement impacts<sup>14,18,27</sup>.

In this regard, spatial prioritisation tools, can help optimise MPA networks based on species distributions<sup>28–32</sup>. Spatial prioritisation analyses

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**Fig. 1** | Spatial prioritisation of commercially important fishery species in European waters using Zonation. Maps show priority ranks based on FAO (top panel) and SAUP (lower panel) biomass weighted (left) and presence-only (right, unweighted) species range data.

allow optimisation across multiple input features representing biodiversity values (e.g., species ranges) to meet multiple pre-defined objectives (usually with a focus on theoretical and estimated protection), resulting in a ranked solution across the area of analysis. This approach has been used internationally to plan and evaluate optimal marine protection measures<sup>30</sup>, and in some cases take into consideration activities and values such as commercial and recreational fisheries<sup>33,34</sup>. It is possible that the geographic distribution of fishery catch biomass and modelled species presence may not align. Thus, the present study maps the optimal areas in European seas using data on both the distribution and catch biomass of commercially important fishery species. Understanding the relationship between where species occur (species presence) and where they are most heavily harvested (catch biomass) will help to explain how an MPA network can be optimally placed to protect biodiversity ecologically (species diversity) and economically (fishery catch).

## Results

### Priority areas

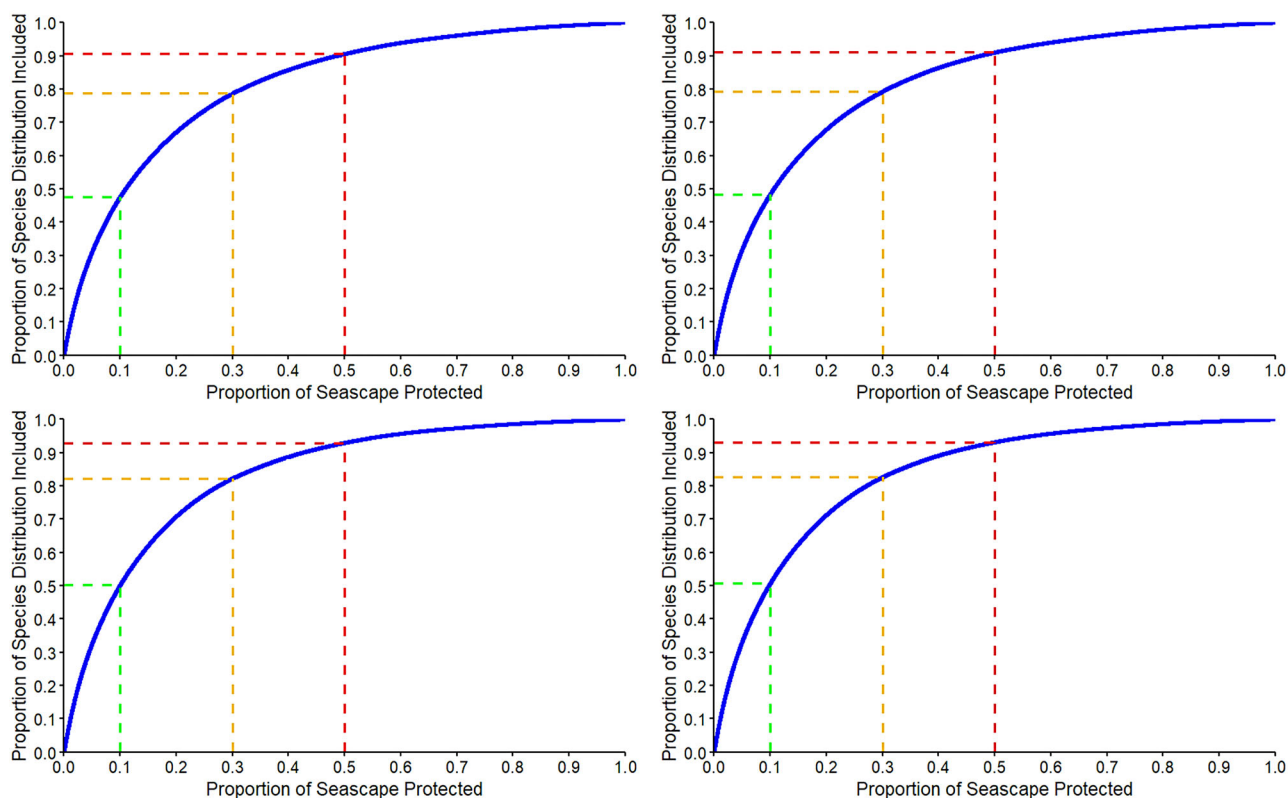
Zonation analysis using fish species recorded from both the FAO and SAUP revealed broadly consistent spatial patterns between the biomass-weighted and unweighted (presence-only) scenarios (Fig. 1, Table 1). In both cases, high-priority areas, where catch biomass-weighted and presence-only scenarios consistently ranked highly, were predominantly concentrated along the Mediterranean, Black Sea and North-East Atlantic coasts, including the Macaronesian islands and Iceland, and continental shelf of the North, Celtic and Irish Seas. Low-priority areas were the deep-sea of the North-East Atlantic, Mediterranean and Black Sea (Fig. 1).

### Performance curves

The mean species performance curves for the FAO and SAUP, weighted and unweighted species' data, were nearly identical, indicating similar levels of

**Table 1 | Jaccard similarity indices and percent spatial overlap between different Zonation prioritisation scenarios at 10%, 30%, and 50% protection levels**

Comparison biomass vs presence	Jaccard Index			% overlap		
	10%	30%	50%	10%	30%	50%
FAO-weighted vs FAO-unweighted	0.97	0.93	0.88	98	96	94
SAUP-weighted vs SAUP-unweighted	0.98	0.95	0.92	99	98	96
FAO-weighted vs SAUP-weighted	0.99	0.98	0.96	100	99	98
FAO-unweighted vs SAUP-unweighted	0.99	0.97	0.97	99	99	98



**Fig. 2 | Species performance curves of commercially important fishery species in European waters using Zonation.** Maps show performance curves based on FAO (top panel) and SAUP (lower panel) biomass weighted (left) and presence-only

(right, unweighted) species range data. The performance curves illustrate the proportion of species distributions as a function of the prioritised area. Dashed lines indicate the top 10% (green), 30% (yellow), and 50% (red) priority areas.

efficiency in representing species distributions relative to the proportion of sea area protected (Fig. 2). The curves exhibited a steep initial rise, suggesting that a small fraction of the area could account for a disproportionately high representation of species distributions. Specifically, for the FAO data, the top 10% of the area includes 45–48% of the species; 30% includes 78–80% of species; and 50% up to 88% of the species’ distributions. For the SAUP data, 10%, 30% and 50% of the area could respectively include 50–51%, 82%, and 92% of the species’ distribution ranges. Thus, the choice of dataset or weighting did not significantly change the prioritisation outcomes. Both approaches demonstrated high optimisation efficiency, although the weighted version maintains a theoretical advantage by explicitly aligning conservation priorities with areas of economic importance in fisheries.

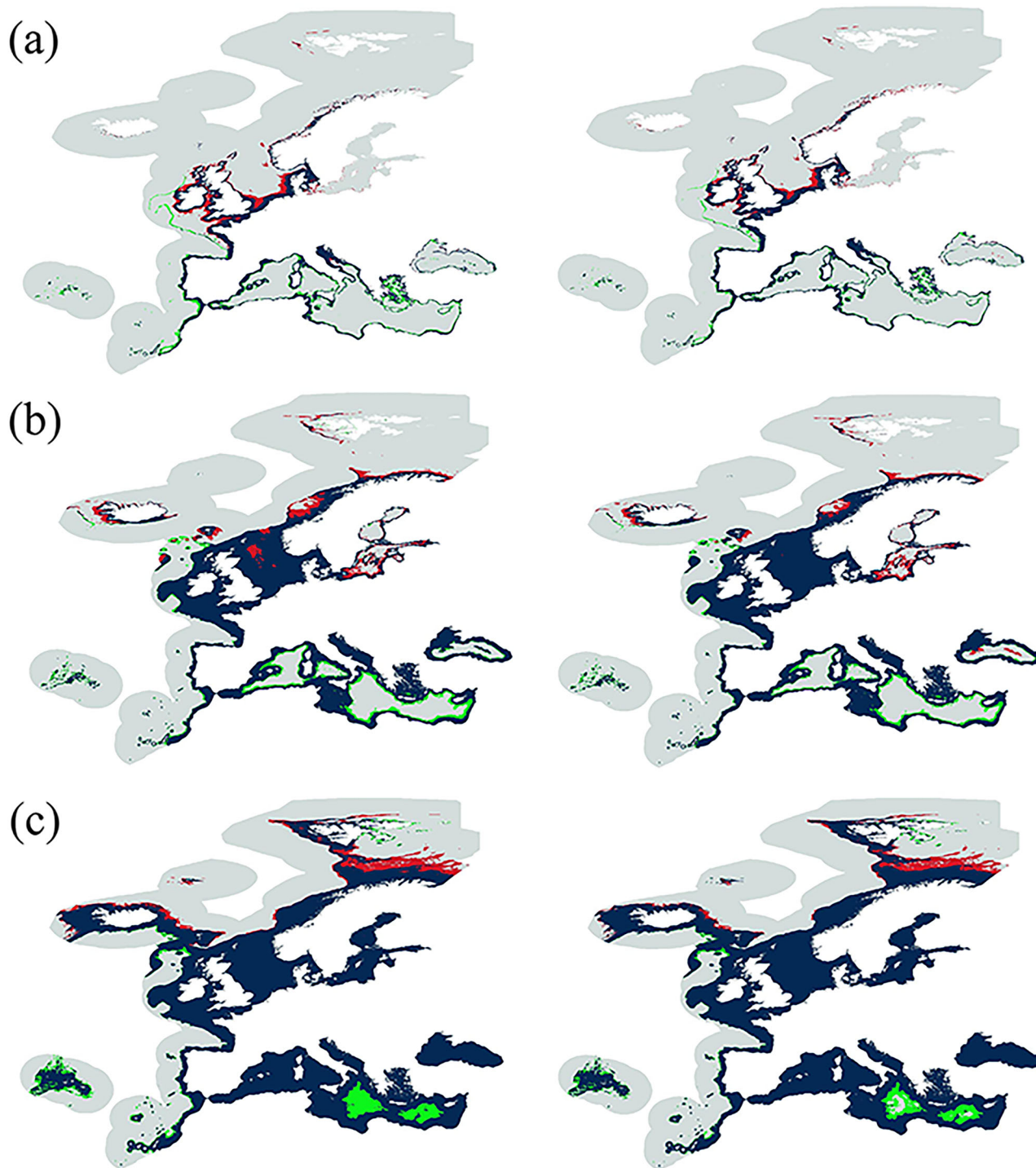
A closer look at the differences in Zonation outputs shows that while the FAO and SAUP datasets greatly overlap, there are differences in areas prioritised under catch biomass compared to species’ presence-only data. The species’ presence only data results for both the FAO and SAUP data gave greater priority to parts of the Mediterranean, Macaronesia, the shelf edge off the Celtic Sea, while the catch biomass gave greater weight to higher latitudes in the North-East Atlantic Ocean from Ireland and Britain to the North Sea and Norway (Fig. 3).

**Correlation between presence-only and biomass-weighted scenarios**

If large-range species had greater catch biomass (e.g., Atlantic herring *Clupea harengus*, blue whiting *Micromesistius poutassou*, Atlantic mackerel *Scomber scombrus*, and Atlantic cod *Gadus morhua*) at a European scale then this should drive differences between the species’ presence and biomass weighted analyses. For the FAO data ( $n = 661$  species) there was a weak but statistically significant negative correlation ( $\rho = -0.107, p = 0.0055$ ) (Supplementary Fig. 1). However, there was no correlation for the SAUP data ( $n = 437$  species) ( $\rho = 0.0037, p = 0.938$ ). This suggests that species with broader or narrower spatial distributions are not systematically associated with higher or lower catch biomass when using the SAUP dataset.

**Stability of prioritisation outcomes**

The Jaccard index values above 0.96 across all comparisons and thresholds confirmed that the spatial prioritisation was highly stable. This is further supported by the corresponding spatial overlap, which exceeded 98% in all pairwise comparisons at the strictest threshold. This high spatial agreement indicates that the prioritisation outputs were consistent across different



**Fig. 3 | Spatial overlap of priority areas between weighted by biomass and unweighted presence of species from FAO (left) and SAUP (right) data across three conservation targets. a Top 10%, b top 30%, and c top 50%. Dark blue is where**

**biomass and presence areas of overlap. Green is where species presence is more prioritised, while red is where catch biomass weighted data are more prioritised.**

input data types and weighting schemes, suggesting a degree of methodological stability in identifying optimal areas.

### Discussion

We found that different fishery data (FAO, SAUP), and variables (presence, catch biomass) lead to very similar priority areas for protection. This indicates that at a European scale, the results would not significantly differ given more data or variation in catch over time. Further, the spatial congruence of these two indicators of biodiversity

suggests that species conservation can generally support fisheries and vice versa (Fig. 1). In addition, the proportion of species that could theoretically be included in the prioritised areas using presence and biomass-weighted were almost identical (Fig. 2). The differences between prioritisation results using presence and biomass data were the greater emphasis on southern Europe areas for presence only, reflecting their higher species richness; and of high latitude North-East Atlantic areas for biomass, reflecting fewer fish species but often of high biomass in those areas.

Both the FAO- and SAUP-derived outputs revealed consistent high-priority areas concentrated along productive coastal regions, particularly the Mediterranean (Eastern Mediterranean, and Adriatic Seas) and parts of the North Sea and Bay of Biscay. These regions are known biodiversity rich spots, historically associated with intensive fishing activity and species richness<sup>35–38</sup>. In addition, the biomass-weighted outputs from both datasets placed greater importance on nearshore and intensively fished areas, which indicates regions with high biomass and economic relevance. This helps prioritise sites that contribute most to fishery productivity and local livelihoods, thereby enhancing both the ecological and socioeconomic outcomes of conservation efforts. Similarly, low-priority areas were consistently found in deeper sea areas, representing regions of fewer species, lower biomass and less commercial exploitation. This is consistent with the known biogeographic gradients in biodiversity, productivity and temperature with depth<sup>39,40</sup>.

The species performance curves observed from both the FAO and SAUP datasets in our study demonstrated that a relatively small proportion of the seascape could efficiently capture a substantial fraction of species distributions. This steep initial rise in the performance curves, as found in previous studies<sup>31,41</sup>, is because the algorithm prioritises the areas with most species in the first instance. In our analyses, the marginal differences between the biomass-weighted and unweighted outputs indicated that the prioritised areas coincided with regions of both higher biodiversity (most species) and economic (most catch biomass) value.

Our performance curves revealed that protecting the top 10% of the seascape captures nearly half (45–51%), and the top 30% of the seascape can capture about 78–82%, of recent species distributions. Similar performance levels have been found in other marine and global studies<sup>30,31</sup>. Prioritising conservation in these areas would benefit fisheries in the long-term through the recovery of (a) population abundance, body size and age structure, and genetic diversity; (b) protection of broodstock and nursery habitats; and (c) spillover effects from fully protected (no-fishing) areas into adjacent fishing zones<sup>14,27</sup>. These high-priority areas will overlap with productive fishing grounds and their designation as fully protected areas may or may not lead to short-term economic impacts. To date, there is no evidence of negative impacts on any fishery due to no-take MPA establishment, but many examples of benefits<sup>14</sup>. However, further restrictions on fishing effort are required in European seas regardless of MPA designation<sup>3</sup>. Thus, setting aside some areas to allow full recovery of all fish populations, thereby eliminating bycatch and high-grading (where less valuable fish are discarded) mortalities, and allowing habitat recovery from bottom trawling, while being transparent and equitable for all fishermen, may prove a more successful fishery management strategy than piecemeal fishing restrictions. Balancing these trade-offs through stakeholder engagement and adaptive spatial planning will be essential to ensure both ecological effectiveness and social equity. Furthermore, as areas are designated for full protection of biodiversity, including fishery species and their food webs, spatial prioritisation analyses can be repeated to optimise where additional areas would maximise conservation benefits. Such robustness is critical for gaining stakeholder confidence in marine spatial planning and policy implementation<sup>42</sup>.

In conclusions, these findings support evidence-based expansion of MPAs toward achieving global 30 × 30 goals with implications for aligning the protection of species and fishery catch in European seas. Future work should compare our findings to other measures of biodiversity, including non-fishery species, species of conservation importance, habitat forming species, and how well existing MPA protect biodiversity. The results of the present study thus provide useful guidance to European policymakers, MPA planners, and fishery managers in their selection of sites with dual mandates: protecting marine biodiversity and providing for long-term fishery sustainability. This alignment ensures that MPAs are not perceived as restrictive but as tools that can enhance long-term fisheries productivity and economic resilience for coastal communities.

## Methods

### Study area

The study area comprised European seas, an area of approximately 10.73 million km<sup>2</sup>, from the Arctic to temperate Atlantic shelf seas, the Baltic, Black and Mediterranean Seas, and the Macaronesian islands and parts of North-East Atlantic.

### Commercially important fish data

We collected species fishery catch biomass data (in tonnes) from two sources: the Food and Agriculture Organization<sup>43</sup> and the Sea Around Us Project<sup>44</sup> (SAUP). The FAO data are reported catch biomass, whereas SAUP provided reconstructed estimates of reported and unreported catch biomass data (including industrial, recreational, artisanal, subsistence, and discard activity). For both the FAO and SAUP datasets, catch biomass data were extracted under the FAO major fishing areas 27 (North-East Atlantic), 34 (Eastern Central Atlantic), and 37 (Mediterranean and Black Sea) (Supplementary Table 1). Marine fishery species catches from 2012 to 2022 from FAO, and 2012 to 2019 for SAUP, were selected to account for any annual variation in reported catches. We calculated the mean catch biomass across years and summed the values across countries to generate total catch biomass for each species. The trends in catch were similar between the FAO and SAUP data (Supplementary Fig. 2).

A total of 841 unique marine species were recorded in European seas from 2012 to 2019 for SAUP and to 2022 for the FAO datasets. Of these, 810 species were reported by the FAO and 476 by the SAUP, with 445 species reported in both datasets. FAO and SAUP datasets differed in species composition and catch, they were analysed separately and compared. Species were excluded if they had unresolved or inconsistent taxonomy or if catch records were aggregated only to genus or family level, as these could not be linked to species-specific spatial distribution models. All species names were standardised based on the World Register of Marine Species (WoRMS) to ensure taxonomic consistency across datasets<sup>45</sup>.

For identified commercially important species, modelled presence-only range maps were downloaded from the MPA Europe project Species Distribution Models (SDM) platform (v1.0) developed by the Ocean Biodiversity Information System<sup>46</sup> (OBIS). These species-specific SDMs were compiled as raster files and served as input layers for further spatial prioritisation analyses in Zonation v5.1.0<sup>29</sup>. This resulted in a filtered list of 681 important taxa including 507 finfish, 73 crustacean and 101 mollusc species, of which 661 species matched the FAO records and 437 matched the SAUP records. These species collectively represent fisheries data reported in 36 European countries, including Albania, Belgium, Bosnia and Herzegovina, Bulgaria, the Channel Islands, Croatia, Denmark, Estonia, the Faroe Islands, Finland, France, Germany, Gibraltar, Greece, Iceland, Ireland, the Isle of Man, Italy, Malta, Latvia, Lithuania, Monaco, Montenegro, the Netherlands, Norway and the Svalbard and Jan Mayen Islands, Poland, Portugal, Romania, Slovenia, Spain, Sweden, the United Kingdom of Great Britain and Northern Ireland, Serbia, and Ukraine.

### Data analysis

The downloaded raster files had a spatial resolution of 0.05° (approximately 5.5 km at the equator), and were pre-processed using R v4.4.2<sup>47</sup> packages, including *dplyr*<sup>48</sup>, *terra*<sup>49</sup>, and *arrow*<sup>50</sup>. We extracted the standard deviation (SD) band from the downloaded SDM outputs and applied the uncertainty discounting approach described by Moilanen et al.<sup>51</sup> and Stephenson et al.<sup>52</sup> to account for model uncertainty. Suitability values were adjusted by subtracting the SD multiplied by a scaling factor ( $\alpha = 0.5$ ), representing a moderate level of discounting<sup>52</sup>. Negative values resulting from this correction were truncated to zero to avoid over-penalisation. Finally, all species range maps were masked to the study area for further analysis in Zonation.

Taxa-specific weightings can be applied to distribution layers in the spatial prioritisation to reflect higher perceived value of prioritising areas suitable for particularly important taxa. The study taxa were weighted based on the average of the total annual catch biomass in metric tonnes for the

years selected (see above) to account for the relative importance of each species within the fishery. As the fishery catch values were highly right-skewed (with a few species dominating the total catch), a  $\log_n(x + 1)$  transformation was applied, where  $x$  represents the total species-specific catch biomass.

Zonation analyses were carried out on species' biomass and presence ranges for the FAO and SAUP data separately using the Core Area Zonation (CAZ1) algorithm in Zonation<sup>29</sup>. Species biomass layers were weighted based on total catch biomass, while presence-only layers were included with equal weights. Zonation sequentially removed cells that contributed the fewest fish species. The CAZ1 algorithm prioritises representativeness of all biodiversity features as opposed to other rules that can be used which maximise biodiversity hotspots or target prioritisation of individual biodiversity features. The resulting output is a single map of fish prioritisation, with areas identified from the highest to lowest priority in terms of conservation value.

To align the results with global and regional policy objectives, the resulting maps show the top 10%, and 30% and 50% priority areas. Other Zonation outputs included the proportion of each taxon's range protected across the study area. At each priority conservation protection level (e.g., the top 10%, 30% and 50%), the ranges of individual taxa contained within these areas can be assessed to explore the extent of protection for each fish species (or averaged to provide information on protection of all fish).

These prioritised areas were compared between the species' presence-only (unweighted), and weighted by catch biomass outputs for both the FAO and SAUP datasets to assess spatial congruence. In addition, the species present in the top 10%, 30% and 50% of the area were compared for both the species' biomass and presence data using Spearman's rank correlation (for continuous comparisons) and the Jaccard similarity index (for binary top-priority overlaps). The Jaccard index is a measure of set similarity<sup>53</sup> that provides a quantitative basis for comparing spatial prioritisation outputs. Values approaching one indicate near-complete overlap, meaning that the intersection of priority areas between scenarios is almost as large as their union. All analyses were conducted in R using  $sp^{54}$ ,  $terra^{49}$ , and  $raster^{55}$ .

### Data availability

All data generated or analysed during this study are included in this published article and its supplementary information files. Spatial prioritisation maps are available in Zenodo MPA Europe repository: <https://doi.org/10.5281/zenodo.16901159>.

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## Author contributions

R.A. Writing-original draft, data curation and conceptualisation; A.M.A. Writing-review & editing, resources, methodology; S.C.P. Writing-review & editing, conceptualisation and supervision; F.S. Writing-review & editing, resources, and supervision; M.K.S. Writing-review & editing, supervision; M.J.C. Writing-review & editing, conceptualisation, resources, methodology, supervision. All authors provided interpretations of the data as well as reviewed and approved the manuscript.

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## Competing interests

The authors declare no competing interests.

## Additional information

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