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Identification of priority cetacean areas in the north-east Atlantic using systematic conservation planning

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Abstract

1. Mobile marine protected areas have been proposed for the conservation of highly seasonal or mobile marine megafauna. However, seasonal data on the distribution of marine wildlife to inform protected areas are generally scarce worldwide, especially for cetaceans, which makes dynamic solutions difficult to implement.
2. Furthermore, conservation objectives are often set at the level of individual species rather than at the community level, despite many species having similar or overlapping habitat requirements, and a comparison of the effectiveness of mobile vs. static Marine Protected Areas options has rarely been done.
3. Systematic conservation planning was used to identify priority areas of cetacean biodiversity in the north-east Atlantic accounting for seasonal changes in distribution. Consistent hotspots across seasons at a community level, in particular along the shelf edge, suggest that fixed priority areas for cetacean biodiversity may be appropriate.
4. The area required for protection to meet conservation targets (i.e. 20% of a population occurring within a protected area) is minimized when considering populations at basin scale rather than national level. Highly mobile megafauna normally exploit persistent and predictable oceanographic features, so a habitat suitability rather than a jurisdiction-based approach is more appropriate.

KEYWORDS

cetaceans, marine mammals, mobile marine protected areas, MPA, prioritizr, systematic conservation planning, transboundary conservation

1 | INTRODUCTION

The ocean is a highly dynamic environment with large variations in currents, wind regime and temperature across space and time (Hobday et al., 2014). Pelagic systems in particular represent variability over large scales, exceeding those in other systems, and driving the mobility of many pelagic species (Hyrenbach, Forney & Dayton, 2000). For example, seasonal thermal stratification of the water column plays a key role in the occurrence of various marine mammal and seabird species (Scott et al., 2010; Cox, Scott & Camphuysen, 2013). Other dynamic features important for the distribution and abundance of marine species include the timing of phytoplankton blooms (Grémillet et al., 2008) with a strong bottom-up effect at higher trophic levels (Praca et al., 2009; Druon et al., 2012) or climatological fronts (Bost et al., 2009). Nevertheless, spatiotemporally predictable characteristics such as topography, and tidal and ocean currents can support high numbers of marine species across multiple trophic levels (Cañadas, Sagarminaga & García-Tiscar, 2002; Genin, 2004; Certain et al., 2008). Within this context, precise knowledge of spatiotemporal changes in species distribution and abundance is crucial to understand population dynamics and ecosystem functioning (Chase & Leibold, 2003; Ehrlén & Morris, 2015) but also to identify priority areas for species persistence (Hoyt, 2012; Evans, 2018).

Highly mobile megafauna, such as cetaceans, sharks, turtles and seabirds are unlikely to be properly protected within small-scale static protected areas owing to their mobility (Hoyt, 2012; Critchley et al., 2018), but some successful examples exist where specific threats can be properly managed locally (e.g. Gormley et al., 2012). Marine megafauna usually exhibit considerable seasonal distribution changes (Campbell et al., 2015; Roberts et al., 2016; Cañadas & Vázquez, 2017), and adjusting management measures to account for seasonal variability in species distribution is important in order to achieve effective species conservation throughout the entire year (Evans & Hammond, 2004; Guisan et al., 2013). Consequently, mobile marine protected areas, such as seasonal closures, may potentially be more suitable for the conservation of highly mobile populations (Hartel, Constantine & Torres, 2014; Dwyer et al., 2020). Conservation planning will therefore greatly benefit from seasonal information on species' habitat preferences, but despite being crucial, this information rarely is included (e.g. Cañadas & Vázquez, 2014; Afán et al., 2018; Giménez et al., 2020). This is particularly important if seasonal variability in distribution is driven by species changing habitat, for example switching from on-shelf to off-shelf habitats or range shifts along a particular habitat (e.g. the shelf edge) (Forney & Barlow, 1998; Neumann, 2001).

Dynamic area-based management (i.e. temporal protection of certain areas based on the seasonal movements of the species) is a promising avenue for conservation of pelagic species, particularly where information on species movement and distribution changes is included (Hazen et al., 2018; Pinsky et al., 2020). This approach has proved to be successful in several cases, such as for the protection of sea turtles and tunas (Hobday et al., 2011; Howell et al., 2015), but is untested more widely (Ortuño Crespo et al., 2020). Despite the fact that information on seasonal patterns of occurrence is essential for a comprehensive conservation strategy (Pratt, Smith & Beck, 2019; Vilas et al., 2020), seasonal monitoring of marine wildlife is generally scarce worldwide. Recently, large-scale data integration, spanning multiple survey platforms, seasons and years, has resulted in the production of monthly modelled density estimates for 12 species of cetaceans inhabiting north-eastern Atlantic waters (Waggitt et al., 2020). This provides a suitable monthly dataset to use decision-making tools to identify whether static or mobile priority areas best meet targets for conservation as required by national and EU legislation (e.g. Habitat Directive (92/43/EEC), Marine Strategy Framework Directive (2008/56/EC)).

Effective conservation through the use of protected areas is largely based on the assumption that activities representing threats to marine biodiversity are limited or excluded from protected areas. In terms of cetacean conservation, fisheries represent one of the greatest risks to populations through prey depletion as well as bycatch (Bearzi, 2002; Hamner et al., 2014; Jaramillo-Legorreta et al., 2019; Peltier et al., 2021). However, fisheries are rarely excluded from protected areas, with a recent study showing that across European waters, habitat-damaging trawling activity was actually more intensive inside protected areas than outside them, and that sensitive species of elasmobranchs were more abundant outside the heavily fished protected areas (Dureuil et al., 2018). Currently fishing activity can be quantified using the Automatic Identification System, which accounts for a large part of the fishing fleet (i.e. vessels larger than 12 m) (Natale et al., 2015; de Souza et al., 2016; McCauley et al., 2016; Vespe et al., 2016; Kroodsma et al., 2018). Such data can help determine the occurrence of fishing activity within cetacean biodiversity hotspots as a potential factor undermining conservation objectives.

The main objective of this study is to identify priority cetacean areas at a community level (i.e. accounting for multiple cetacean species that may have similar or overlapping habitat requirements), and evaluate whether dynamic (i.e. monthly or seasonal priority areas) or static (i.e. all year-round priority areas) area-based approaches may be most appropriate within the scale of the north-east Atlantic. The main hypothesis is that despite known seasonal movements of cetaceans, persistent priority areas may occur across years and seasons owing to predictable oceanographic conditions that promote productivity, and hence suitable habitat for those species. Furthermore, the effect of setting conservation targets at a basin (i.e. European level) vs. national level (i.e. exclusive economic zone waters) was evaluated. Finally, the co-occurrence of fishing effort was explored within priority areas, given that prey removal and incidental capture in fishing gear are major threats affecting cetacean populations worldwide.

2 | MATERIAL AND METHODS

2.1 | Data

Density distribution maps of cetaceans (animals/km^2) inhabiting the exclusive economic zones (EEZs) of countries in the north-east Atlantic, specifically the EEZs of (north to south) Norway, UK, Ireland, Sweden, Denmark and Germany, The Netherlands, Belgium, Atlantic France and north-west Spain were obtained from Waggitt et al. (2020), who modelled the monthly density distribution of 12 cetacean species (*i.e.* Atlantic white-sided dolphin (*Lagenorhynchus acutus*), bottlenose dolphin (*Tursiops truncatus*), fin whale (*Balaenoptera physalus*), harbour porpoise (*Phocoena phocoena*), killer whale (*Orcinus orca*), long-finned pilot whale (*Globicephala melas*), minke whale (*Balaenoptera acutorostrata*), Risso's dolphin (*Grampus griseus*), short-beaked common dolphin (*Delphinus delphis*), sperm whale (*Physeter macrocephalus*), striped dolphin (*Stenella coeruleoalba*), white-beaked dolphin (*Lagenorhynchus albirostris*)) at 10 km resolution using a range of dedicated and opportunistic survey platforms from 1980 to 2018. This is the most complete dataset in European waters on seasonal distribution of cetaceans available at a basin scale. Nevertheless, interannual differences were not taken into account and only general seasonal habitat associations were the focus of the analysis (Waggitt et al., 2020). As the modelled monthly distributions represent long-term averages across several decades, harbour porpoise, a widespread and abundant species which has shown substantial changes in distribution in recent decades (Hammond et al., 2013; Gilles et al., 2015), was omitted. However, in contrast to harbour porpoises, substantial changes in distribution across recent decades have not been recorded in most species (Evans & Waggitt, 2020), suggesting that modelled distributions are a good representation of long-term distributions in most cases.

2.2 | Prioritization analysis

Spatiotemporal prioritization to define priority cetacean areas was performed using the R package *prioritizr* (Hanson et al., 2023). The package uses species distribution data to optimize priority areas based on user defined conservation objectives, conditions and penalties. Here, the area required to encompass 20% of all species' abundance was minimized within the basin area. This specific target was set because the IUCN suggested this target as the minimum amount of each habitat or species to be represented in marine reserves (IUCN World Parks Congress, 2003) and it has been applied to several studies (e.g. Morfin, Bez & Fromentin, 2016; Afán et al., 2018). The planning unit (i.e. the building blocks of any prioritization exercise) resolution was designed to have the same resolution as cetacean abundance data, as recommended by Hermoso & Kennard (2012).

Two different scenarios were considered: *scenario A* for encompassing 20% of all species' abundance at a basin level (i.e. north-east Atlantic); and *scenario B* for encompassing 20% of all species' abundance within each country's EEZ. Furthermore, each scenario was rerun calibrating the boundary of the solution to obtain compact solutions (i.e. with fewer boundaries). In this calibration the *add_boundary_penalties* parameter of *prioritzr* was used to favour solutions that spatially clump planning units together based on the overall boundary length (perimeter). This parameter is equivalent to the boundary length modifier parameter in *Marxan* (Ball, Possingham & Watts, 2009).

2.3 | Persistence of priority areas

Seasonal persistence of priority areas was assessed by performing a frequency map of monthly solutions. Higher frequencies imply a higher selection of areas, indicating that priority areas do not differ markedly between months. Thus, these areas should be considered *persistent* priority areas. Conversely, areas with low values indicate areas that are only a priority during certain months and suggest a dynamic scenario. Cohen's kappa coefficient was used to quantify the similarity between different monthly priority solutions (Ban, Picard & Vincent, 2009). All pairwise comparisons between months were performed but the values of the diagonal (see Figure S2) are particularly important because they indicate the similarity in priority areas between consecutive months. The categorization of Cohen's kappa coefficient was done following Landis & Koch (1977), where a value of 0 is 'No agreement', 0–0.2 is 'Slight agreement', 0.2–0.4 is 'Fair agreement', 0.4–0.6 is 'Moderate agreement', 0.6–0.8 is 'Substantial agreement' and 0.8–1.0 is 'Almost perfect agreement'. In addition, a cluster dendrogram was generated between the spatial prioritization solutions to quantify the existence of clusters of solutions (Linke et al., 2011). Finally, the priority area in each month was quantified for each scenario to evaluate how different decisions (i.e. EEZ vs. European target and boundary calibration) affect the total area identified.

2.4 | Fishing activity

Fishing effort (i.e. number of Automatic Identification System messages detected as fishing) in the north-east Atlantic was extracted from Global Fishing Watch dataset from 2012 to 2016 (https://globalfishingwatch.org). Daily information was summarized by month and fishing gear type (i.e. drifting longlines, fixed gears, purse seines, trawlers and other fishing) in R. The percentage of fishing effort inside cetacean priority areas within each country EEZ irrespective of the country of origin of the boats was calculated with the *Zonal Statistic Tool* in ArcMap 10.7.1 for scenarios A and B.

3 | RESULTS

3.1 | Prioritization analysis

The spatiotemporal prioritization analysis shows that within the north-east Atlantic, priority areas are concentrated in the waters of four different countries: the UK, Ireland, France and Spain (scenario A, Figures 1a, S1a, Table S1). When protection targets (i.e. 20% for each species) were established to be met by each country within their own EEZ (scenario B, Figures 1b, S1b), the area required increased markedly (Figure 2), but retained areas identified in scenario A. Areas identified as priority for cetaceans were mainly concentrated in the north-west of Scotland, offshore Irish and French waters, as well as coastal and offshore areas of north-west Spain.

Cohen's kappa matrix, which indicates the similarity between months, displayed consistent values (Figure S2a), suggesting that priority areas are consistent throughout the year. Values in the diagonal represent almost perfect agreement (Figure S2a), suggesting high agreement in the priority areas month-to-month. The same pattern is present in scenario B despite setting targets at country level (Figure S2b). Cluster analysis suggests two differentiated clusters despite the high agreement in Cohen's kappa values, with one cluster from November to June and another from July to October (Figure S3a,b).

When the boundary of the solutions is calibrated (Figures 1c,d and S1c,d) to obtain more compact solutions, three well-defined areas

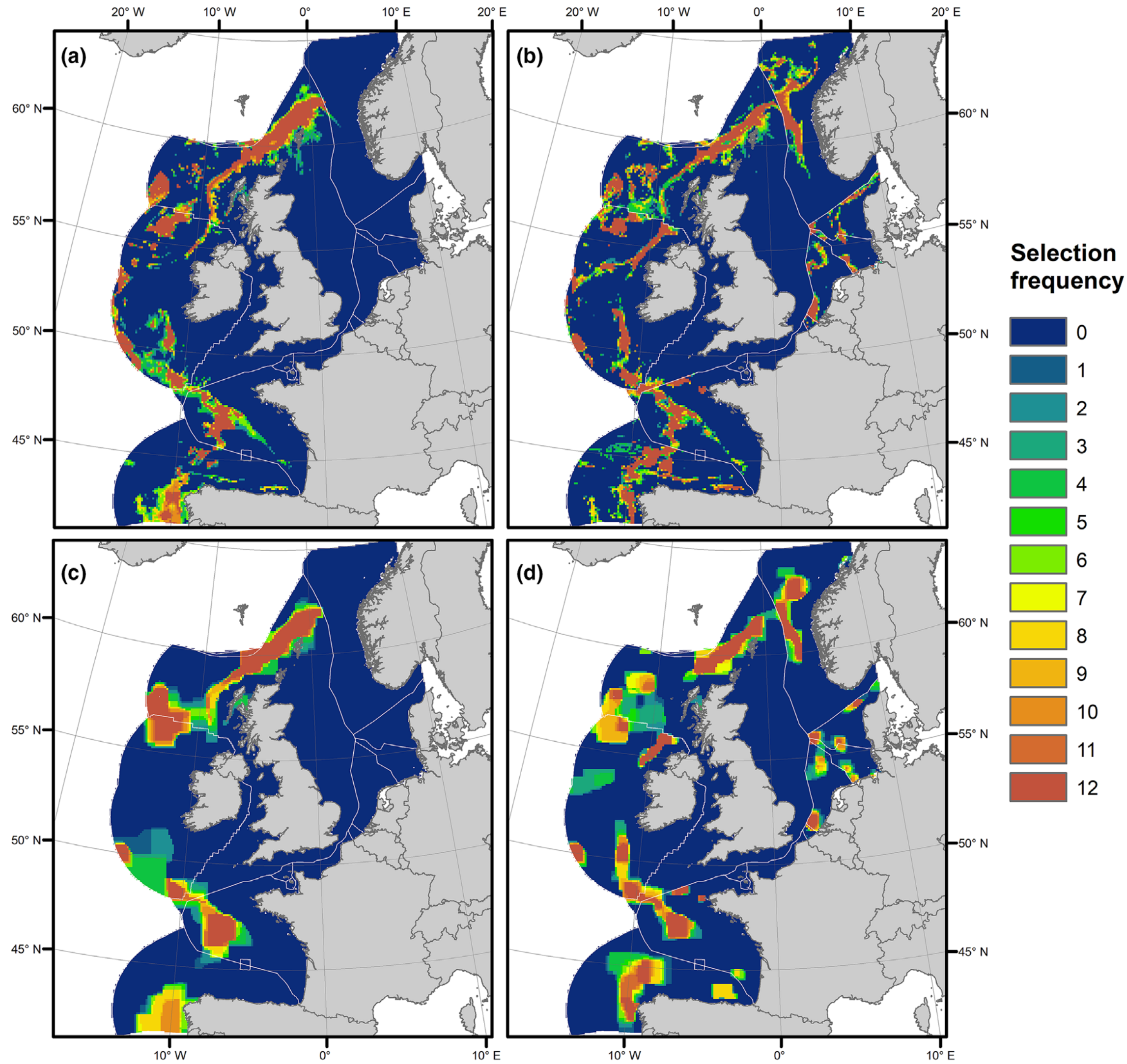

FIGURE 1 Frequency of all best solutions for: (a) scenario A1 – protection target at basin level without boundary calibration; (b) scenario B1 – protection target at country level without boundary calibration; (c) scenario A2 – protection target at basin level with boundary calibration; and (d) scenario B2 – protection target at country level with boundary calibration.

emerge: the north-west offshore waters of Scotland and north of Ireland; the offshore waters off southern Ireland and France; and the coastal and offshore waters in north-west Spain. When planning at country level (scenario B) with boundary calibration (Figure 1d), the identified areas at basin level generally persist, but additional areas emerge to meet national targets (Figure 1d), such as the offshore waters of Norway, waters on the EEZ borders of Denmark, Germany and The Netherlands, and in offshore waters in the Basque country (Spain). Cohen's kappa values are generally lower, indicating reduced similarity across months (Figure S2c,d) compared with prioritization without boundary calibration (Figure S2a,b). Nevertheless, months cluster in a similar way to scenario A with months from November to June clustering together (Figure S3c,d).

The area required to protect 20% of all species' abundance at EEZ level (scenario B; mean area, 296,071.0 km^2 (minimum, 291,604.3 km^2 to maximum, 299,904.3 km^2)) is almost 20% larger than when planning at basin level (scenario A; mean area, 247,861.7 km^2 (minimum, 243,503.4 km^2 to maximum, 250,003.4 km^2), see Figure 2). In addition, calibrating the boundary of the solutions increases the area requirements because in order to reduce the overall number of discrete solutions, a greater area is needed across fewer sites to achieve the same target (Figure 2). Seasonal area requirements are similar between scenarios with the total area required between January and May being smaller than that for the rest of the year.

3.2 | Fishing activity

The proportion of fishing activity occurring inside priority areas on a country-by-country basis was highly variable (Figure 3). France had the lowest proportion of fishing effort within priority areas overall, while the UK had the greatest proportion, indicating a high degree of overlap between priority areas and fishing activity. Fishing activity within priority areas occurred throughout the year, with no consistent seasonal pattern across countries. Some countries showed a relatively consistent proportion of fishing activity within priority areas across the year (e.g. Netherlands, Norway, Spain), while others had peaks at different times of the year, probably representing different seasonal fisheries. Longliners and fixed gears were more prevalent within priority areas in France, Ireland, the UK and Spain, while The Netherlands, Germany and Belgium had a higher proportion of trawlers and other, 'undesignated' gears in their priority areas.

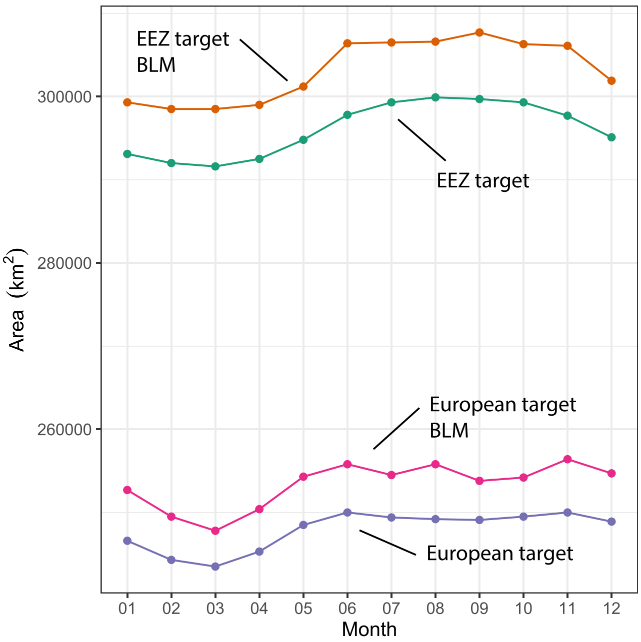

FIGURE 2 Area (in km^2) of priority cetacean areas selected when using a European target (purple, boundary not calibrated; pink, boundary calibrated) or when the target has to be fulfilled in each country EEZ (green, boundary not calibrated; orange, boundary calibrated).

4 | DISCUSSION

Identifying priority areas that cover the full annual cycle for cetaceans is a complex task, as species distribution changes seasonally. Few studies have generated the kind of data required to account for such variability (Becker et al., 2014; Roberts et al., 2016; Laran et al., 2017). Here, spatiotemporal dynamics (i.e. seasonal species distribution models) have been included in the identification of priority areas for cetaceans at a community level.

Dynamic area-based solutions for the conservation of marine wildlife are becoming more common in different ocean basins and can be especially useful to avoid specific threats, for example, boat collisions, when focused on a single migratory species (Dunn et al., 2016; Ortuño Crespo et al., 2020). Despite arguments that cetaceans require mobile protected areas for their conservation (Hoyt, 2012), this study suggests that when including multiple species and setting targets at a basin scale, protected areas become large enough for fixed approaches to work effectively. An optimal MPA design should protect the distribution of populations during the whole year, encompassing seasonal differences in distribution (Hoyt, 2012). The persistence of large priority areas for cetaceans identified in this study suggests that these species do not distribute randomly, and

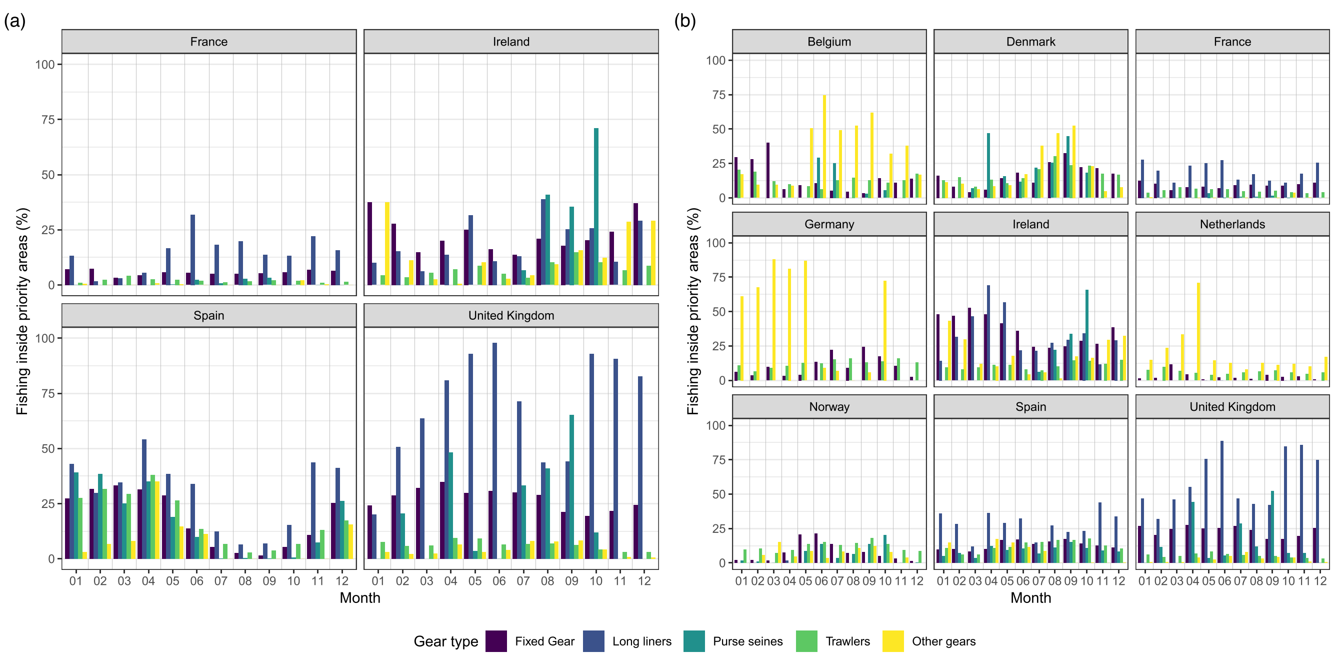

FIGURE 3 Percentage of the fishing effort inside priority cetacean areas for each fishing gear in each month for each country. (a) Conservation target at European level (scenario A); and (b) conservation target at EEZ level (scenario B).

probably concentrate in areas of high productivity and prey abundance. As such, at a multispecies community level, static solutions are a suitable approach to encompass at least the 20% of each cetacean species occurring in the NE Atlantic. This basin is a shelf-sea area dominated by topographically driven processes linked to the movement of persistent and predictable tidal and ocean currents (Cox et al., 2018). With static approaches, monitoring presents fewer challenges for enforcement, and is easier to implement across multiple stakeholders (Pérez-Jorge et al., 2015) than dynamic approaches (Maxwell et al., 2015). Furthermore, static protection provides continuous protection of benthic habitats, potentially enhancing the wider ecosystem (Brander et al., 2020; Duarte et al., 2020).

The increased area required when setting conservation targets at country level (i.e. EEZ level) as opposed to basin level gives support to the argument for setting priority areas for cetaceans across national jurisdictions. Species distributions and oceanographic features do not match national borders, so collaboration between countries in conservation planning is essential to reduce planning costs while ensuring the achievement of conservation targets (Mazor, Possingham & Kark, 2013; Kark et al., 2015). Our results suggest that the identification of priority areas for cetacean species could be done at the European level, reducing the total area required to encompass the 20% of the abundance of each species (Figure 2). However, such an approach places disproportionate responsibility for conserving species at a European level onto a limited number of countries with additional costs associated with monitoring and enforcement. In this case, priority areas are concentrated in the offshore waters off north-west Scotland, the north of Ireland, southern Ireland and France, and the coastal and offshore waters in north-west Spain (Figure 1). Furthermore, there may be knock-on economic effects including potential exclusion of commercial activities including fisheries within identified areas. However, in support of a national-level designation process, an increase in the extent of priority areas required to meet country-level conservation targets may provide greater resilience against catastrophic events and climate change through overall greater area and habitat protection.

Our spatial prioritizations only contain area as a cost but do not include other cost proxies, for example fishing effort as a cost, because the objective was to identify multispecies priority areas and investigate their seasonal persistence rather than identifying areas for the designation of cetacean MPAs. Nevertheless, fishing effort within identified priority cetacean areas was visualized to provide some indication of potential risk to species as well as socio-economic cost if fishing should be excluded from priority cetacean areas. Temporal dynamism of fishing effort inside priority areas shows that this pressure is not homogenously distributed temporally or spatially. Despite the great advance in spatial analysis of marine threats (Halpern et al., 2008; Micheli et al., 2013), future research should focus on the development of spatiotemporal analysis of marine threats (e.g. Kroodsma et al., 2018) to inform conservation actions.

This study is the first to explore priority areas for cetaceans at a community level and across large marine ecosystem/basin scales. While single-species approaches are useful for targeted conservation, a community-based approach provides a more holistic strategy where all species in the community are taken into account in order to achieve Good Environmental Status for European waters, species and habitats (Authier et al., 2017b). In addition to the distribution of cetaceans, potential MPA designation should also take into account the spatiotemporal patterns of threats such as fishing, noise exposure and ocean pollution (Evans, 2018) as well as appropriately engaging stakeholders.

While the distribution maps used in the analyses are novel in providing monthly estimates for common cetacean species in European waters (Waggitt et al., 2020), it needs acknowledging that these represent modelled averages using data collected across several decades with often patchy seasonal coverage in any year. Therefore, seasonal movements could be partly confounded by interannual variability in distribution in the distribution maps. Indeed, such scenarios were highlighted by Waggitt et al. (2020) when discussing limitations of the underlying distributions used in this study. However, substantial changes in distribution across recent decades seem absent in most species except harbour porpoise (Evans & Waggitt, 2020), suggesting that seasonal variability in occurrence is well represented. Therefore, while we urge caution in the absolute locations of the priority areas identified, we believe that they do represent persistent priority areas for the cetacean community in the north-east Atlantic. Indeed, the identification of priority areas at the continental shelf-edge, associated with persistent upwelling and productivity across summer and winter months, is not surprising given our ecological knowledge of these habitats (Cox et al., 2018).

In conclusion, these results suggest that a static rather than dynamic approach to MPA designation is appropriate for the cetacean community in the north-east Atlantic. However, more information should be gathered for long-distance migrants including baleen whales, where a more dynamic protection strategy (Pérez-Jorge et al., 2020) may be required for the conservation of individual species. The large priority areas identified for cetaceans highlight the need for consideration of threats to cetaceans in those areas (e.g. noise, fisheries, maritime traffic, etc.; Authier et al., 2017a). A conservation approach using a community-level strategy would certainly be advantageous, as single-species strategies are unable to preserve ecosystem-based balance as they only focus on a particular species.

AUTHOR CONTRIBUTIONS

Joan Giménez conceived the study, Joan Giménez performed the analysis, Joan Giménez led the writing of the manuscript with input from Mark Jessopp and James J. Waggitt. All authors contributed to subsequent revisions and approved the final version.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

DATA AVAILABILITY STATEMENT

The cetacean distribution maps used for this study are available via the Dryad Digital Repository 10.5061/dryad.mw6m905sz (Waggitt et al., 2020).

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SUPPORTING INFORMATION

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