frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 23 January 2026
DOI 10.3389/fmars.2025.1706011

Check for updates

OPEN ACCESS

EDITED BY
Roberto Carlucci,
University of Bari Aldo Moro, Italy

REVIEWED BY
Benjamin de Montgolfier,
Consultant, Sainte-Luce, Martinique
Carla Cherubini,
Politecnico di Bari, Italy

*CORRESPONDENCE
Camilla Aiuti
camilla.aiuti@gmail.com

RECEIVED 15 September 2025
REVISED 23 December 2025
ACCEPTED 30 December 2025
PUBLISHED 23 January 2026
CORRECTED 12 March 2026

CITATION
Aiuti C, Seveso D, Correia AM, Oliveira N and Marques TA (2026) Spatial-based management for cetacean conservation: a Portuguese coast case study. *Front. Mar. Sci.* 12:1706011. doi: 10.3389/fmars.2025.1706011

COPYRIGHT
© 2026 Aiuti, Seveso, Correia, Oliveira and Marques. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Spatial-based management for cetacean conservation: a Portuguese coast case study

Camilla Aiuti[1,2]*, Davide Seveso[1,3], Ana Mafalda Correia[4], Nuno Oliveira[5] and Tiago A. Marques[2,6,7]

[1]Department of Earth and Environmental Sciences (DISAT), University of Milano-Bicocca, Milan, Italy, [2]CEAUL–Centro de Estatística e Aplicações, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal, [3]MaRHE Center (Marine Research and High Education Center), Magoodhoo Island, Faafu Atoll, Maldives, [4]CIIMAR/CIMAR LA, Interdisciplinary Centre of Marine and Environmental Research, University of Porto, Terminal de Cruzeiros do Porto de Leixões, Matosinhos, Portugal, [5]Sociedade Portuguesa para o Estudo das Aves, Lisboa, Portugal, [6]Centre for Research into Ecological and Environmental Modelling, The Observatory, University of St Andrews, St Andrews, United Kingdom, [7]Departamento de Biologia Animal, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal

Cetaceans are critical indicators of ecosystem health, yet face significant threats from overfishing, habitat loss, and climate change. Key conservation strategies in the EU include Marine Protected Areas (MPAs), the Natura 2000 network, and Important Marine Mammal Areas (IMMAs). This study investigates cetacean distribution along the Portuguese coast from 2004 to 2020, focusing on their presence inside and outside three protected areas, the Sites of Community Importance (SCI) of Maceda-Praia da Vieira and Costa Sudoeste, the Arrábida MPA. We analyzed five cetacean species— bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*), striped dolphin (*Stenella coeruleoalba*) and pilot whale (*Globicephala* spp.)—modeling their total number of sightings and individuals using Generalized Additive Models (GAMs). Through these models, we assessed the impact of habitat-based, geographical, and MPA-related predictors on cetacean presence. Findings showed higher cetacean prevalence in non-protected areas, followed by Maceda-Praia da Vieira and Costa Sudoeste SCIs, with no sightings in Arrábida SCI. Habitat variables had a stronger impact on encounter rates than MPA status. These findings underscore the need to identify and protect specific, data-driven areas of special importance for cetacean communities.

KEYWORDS

biodiversity, cetacean conservation, ecological modelling, marine protected areas, species distribution

1 Introduction

Cetaceans are highly vulnerable to a variety of human-induced pressures, including chemical (Tanabe, 2002; Remili et al., 2024) and plastic pollution (Zantis et al., 2021; Rodríguez et al., 2023), noise disturbance from seismic surveys and shipping (Erbe et al., 2019), oil and gas exploration (Farmer et al., 2018), and bycatch or depletion of prey due to overfishing (Lewison et al., 2004; Bearzi et al., 2006). Given the complex and cumulative nature of these threats, long-term monitoring is essential to detect trends, understand species vulnerability, and inform the development of effective management measures (Evans and Hammond, 2004; Papastravou et al., 2017; Braulik et al., 2018).

The establishment of Marine Protected Areas (MPAs) represents a key strategy in marine conservation efforts (Edgar et al., 2014; Horta E Costa et al., 2025). MPAs can be highly effective when accompanied by specific management plans, enforcement mechanisms, and ecological monitoring, as they can restrict or regulate activities such as fishing, shipping, or resource extraction (Horta E Costa et al., 2016). MPAs have been shown to yield positive outcomes for cetacean populations, including increased abundance and reduced human disturbance (Magera et al., 2013; Grau et al., 2022). Despite these efforts, MPAs currently protect less than 10% of the global ocean surface (Kriegl et al., 2021).

Within the European Union, protection for cetaceans is provided under the EU Habitats Directive 92/43/EEC (Council of the European Communities, 1992), which aims to ensure the maintenance or restoration of natural habitats and species of community interest at a favorable conservation status. Annex II of the Directive, lists species whose conservation requires the designation of Sites of Community Importance (SCIs), that host habitats essential for their survival and reproduction. Once these sites are adopted by the European Commission, they must be designated as Special Areas of Conservation (SACs), requiring the implementation of a management plan; these sites collectively form the Natura 2000 network. Among cetaceans, two species are listed under the Annex II of the EU Habitats Directive: the bottlenose dolphin (*Tursiops truncatus*) and the harbor porpoise (*Phocoena phocoena*). All cetacean species are listed in the Annex IV of the Directive, which ensures strict protection by prohibiting deliberate capture, killing, and disturbance, though it does not mandate specific conservation areas. SACs are recognized as effective tools to support conservation efforts and identify spatial vulnerability hotspots for cetaceans (Cañadas et al., 2005; Cheney et al., 2014).

Important Marine Mammal Areas (IMMAs) are a non-binding spatial tool developed by the IUCN Marine Mammal Protected Areas Task Force to identify areas of critical habitat for marine mammals, based on criteria such as species richness, life-cycle requirements and vulnerability (Tetley et al., 2022). In 2021, the Atlantic Coast of the Iberian Peninsula was designated as an IMMA (IUCN-MMPATF, 2024) based on its ecological significance for several marine mammal species, including common dolphin (*Delphinus delphis*), bottlenose dolphin, harbor porpoise, fin whale (*Balaenoptera physalus*), common minke whale (*Balaenoptera acutorostrata*), Risso's dolphin (*Grampus griseus*), long-finned pilot whale (*Globicephala melas*) and short-finned pilot whale (*Globicephala macrorhynchus*). Although IMMAs do not carry legal protection, they serve as a scientific basis to inform marine spatial planning, environmental impact assessments, and the designation of legally binding MPAs. Given the high mobility of cetaceans and their tendency to range across vast ocean areas, a well-connected and complementary network of protected areas is essential for ensuring effective and adaptive conservation strategies (Notarbartolo Di Sciara, 2008).

Portuguese waters are an important hotspot for cetacean diversity and conservation, hosting approximately 30 cetacean species (Moura et al., 2019). Several of the species recorded in this study, have recently undergone conservation status reassessment (Moura et al., 2019): the fin whale, common minke whale and Risso's dolphin are categorized as vulnerable, while the common dolphin is classified as near threatened and the harbor porpoise is classified as critically endangered. These species, along with others present in Portuguese waters, face various threats due to accidental captures (Sequeira and Ferreira, 1994; Wise et al., 2007; Marçalo et al., 2015; Vingada et al., 2015; Ângelo, 2020), vessel collisions and coastal fishing gear (Ferreira, 2007; Ferreira et al., 2016; Carvalho, 2018). Many of these threats are concentrated in Portugal's contiguous zone (United Nations, 1982), which is the most intensively used maritime area within Portuguese waters, due to fishing and commercial shipping (Global Fishing Watch, 2023). Within this zone, the Portuguese coast includes sites designated to mitigate threats (Figure 1), with specific efforts targeting cetacean species. The Maceda-Praia da Vieira SCI (PTCON0063) was designated under the Habitats Directive of the European Union (Council of the European Communities, 1992), with the European Commission (2001) identifying and protecting the two Annex II species: the harbor porpoise and the bottlenose dolphin. The Arrábida area is both a SCI (PTCON0010) and a fully implemented SAC and MPA (OSPAR Commission, 1992). It is managed through a zoning system that includes fully protected, partially protected, and buffer zones. These regulations specifically aim to mitigate anthropogenic pressures such as fishing and maritime traffic and contribute to the conservation of bottlenose dolphin through habitat preservation and regulation of human activities (European Environment Agency (EEA), 2020). Finally, Costa Sudoeste is designated as a SCI (PTCON0012) under the Habitats Directive and aims to protect the harbor porpoise and the bottlenose dolphin (European Commission, 2001). While Maceda-Praia da Vieira and Costa Sudoeste recognize the ecological relevance of the area for cetacean species, they are not implemented as SACs. The absence of a management plan and enforcement mechanisms currently limits their conservation impact (Frazão Santos et al., 2015).

Although data on the distribution and threats to cetaceans in Portuguese waters exist (*e.g.* Moura et al., 2019), understanding of the long-term effectiveness of current spatial-based conservation measures remains limited.

Species distribution models (SDMs) are widely used in marine ecology to investigate spatial patterns of species occurrence and their relationships with environmental variables, providing a

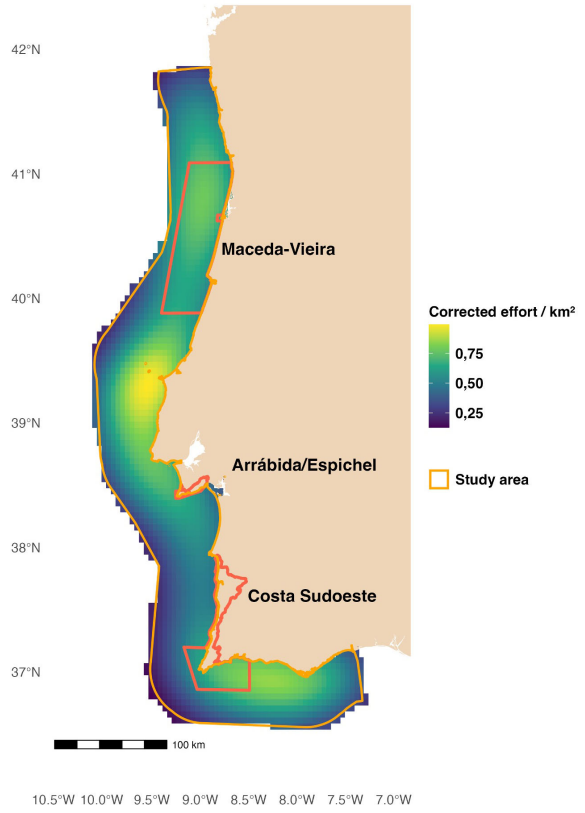


FIGURE 1
Kernel density map of corrected survey effort along the Portuguese coastline (2004-2020). Corrected effort was aggregated within 5 × 5 km grid cells and smoothed using a 30 km Gaussian kernel. Colors indicate kilometers surveyed per km^2, with warmer tones showing higher intensity. Study area boundaries are shown in orange and protected sites are outlined in red.

framework to identify key habitats and inform conservation planning (Guisan et al., 2013; Melo- Merino et al., 2020; Klaassen et al., 2025). Among SDMs, Generalized Additive Models (GAMs) are particularly suitable for modelling complex and non-linear relationships, which are common in marine systems for highly mobile species such as cetaceans (Becker et al., 2020; Pasanisi et al., 2024). Several studies have applied GAMs to investigate species–environment relationships for cetaceans in Portuguese waters (Correia et al., 2015, Correia et al., 2021; Martins et al., 2025). Our focus is on multi-species, long-term data to investigate how cetacean distributions correspond with existing MPAs, highlighting the ecological relevance of key spatial habitat features. This study aims to examine the distribution of cetacean species along the Portuguese coast, specifically within the contiguous zone of 24 nautical miles, using cetacean occurrence data collected from 2004 to 2020. The initial focus was to determine whether cetaceans are more commonly encountered within or outside the three designated protected areas established with cetacean conservation goals. Subsequently, the study models the total number of sightings and individuals of five selected cetacean species: bottlenose dolphin, common dolphin, Risso's dolphin, striped dolphin (*Stenella coeruleoalba*) and pilot whales (*Globicephala* spp.) to understand the spatial variables impacting their presence, ultimately providing insights into the effectiveness of protected areas in cetacean conservation.

2 Materials and methods

2.1 Data collection

The effort-based cetacean occurrence data was provided by the Portuguese Society for the Study of Birds and was collected between 2004 and 2020 by experienced observers onboard several types of vessels (*e.g.* motor vessels or sailing boats), using the European Seabird at Sea Methodology (ESAS) (Tasker et al., 1984). Instituto Português do Mar e da Atmosfera (IPMA) conducted annual surveys primarily designed for stock assessment of small pelagic fishes in Portuguese waters, generally during spring and autumn. The IPMA vessels ranged from 46 to 70 m in length, with observation platforms positioned 5 to 15 m above sea level and navigated at speeds ranging from 6 to 10 knots, depending on vessel type, weather, and sea conditions. Although not originally designed to monitor cetaceans, these surveys were also used to collect data on marine megafauna, including dolphins, seabirds, and turtles. In addition, opportunistic surveys were carried out from smaller vessels (12–15 m long), with observation platforms 2–5 m above sea level. Trained observers systematically recorded megafauna sightings whenever possible. Finally, to complement spatial gaps in IPMA coverage, dedicated surveys were conducted in selected years; these improved overall spatial coverage but did not provide the balanced temporal replication required for robust seasonal analyses.

The survey vessels followed a linear transect. Transects were primarily oriented perpendicular to the coastline, although in some cases they followed a zigzag pattern or lacked a systematic orientation due to local navigational constraints. All observers were previously trained in cetacean ID and on the ESAS methodology, with all participants having prior experience in marine megafauna surveys using this protocol. Observers were positioned at the bow of the vessel searching forward (*i.e.* in the direction of the vessel movement) and to one side of the vessel. The set-up for data collection was a 90 degrees angle of view to be selected from bow to beam, based on the side of the vessel that afforded the best combined viewing conditions. For all survey types, a strip transect protocol was used: mammals observed within a 300 m distance band on one side of the vessel were recorded, creating a surveyed rectangle of known area. The 300 m distance band was delineated in the field using a rangefinder. This area was then surveyed by a two-person team: one observer relayed sightings verbally, while the second recorded data either on paper forms or using an electronic application (©CyberTracker). In cases where only one observer was present, data quality was ensured by their experience and by taking regular breaks to minimize fatigue. For surveys exceeding eight hours of continuous observation effort per day, a second team of two observers was used to allow for rotation. GPS position data were recorded throughout the surveys using handheld GPS devices or the CyberTracker app. Survey effort was

suspended in sea conditions exceeding Beaufort scale 5 (>39 km·h^{-1}). All mammals observed were identified, counted, and their behavior was recorded. Only observations of mammals within a 300 m range on one side of the vessel were considered. The sightings range from the Portuguese Continental coast to the Madeira and Azores waters. A summary of survey protocols, vessel characteristics, and sampling design is provided in Supplementary Table S1 (Supplementary Materials). Our analysis was focused exclusively on the data until the 24 nm (≈44.4 km) (contiguous zone) offshore off the Portuguese Continental coast (Figures 1, 2). .

2.2 Data processing

Data were stored in tabular format, with survey effort linked to associated sightings. On average, each effort point corresponded to about 0.96 km (mean effort) with an interquartile range of 0.39 km. Erroneous data points, such as sightings recorded on land, were excluded. To account for detectability, a correction factor was applied to each effort segment based on sea state and visibility conditions. Detectability levels were defined by combining sea state and visibility into categorical classes, and a correction factor was calculated as the ratio of sightings per unit effort normalized by the highest value across all classes. Corrected effort was obtained by multiplying observed effort (km travelled) by this factor, ensuring comparability across different sighting conditions (see Supplementary S2 for details). This detectability-corrected effort ensures more accurate comparison of cetacean occurrence across varying environmental conditions. For comparison, an uncorrected survey effort map is also provided (Supplementary Materials S3). Data analysis was performed using QGIS Version 3.30, with all spatial data projected in WGS84. The study area included territorial waters, and the contiguous zone (24 nautical miles from baseline) of continental Portugal, defined using shapefiles from the Marine Region repository (https://www.marineregions.org/downloads.php). Marine Protected Areas shapefiles were sourced from Protected Planet (https://www.protectedplanet.net/en).

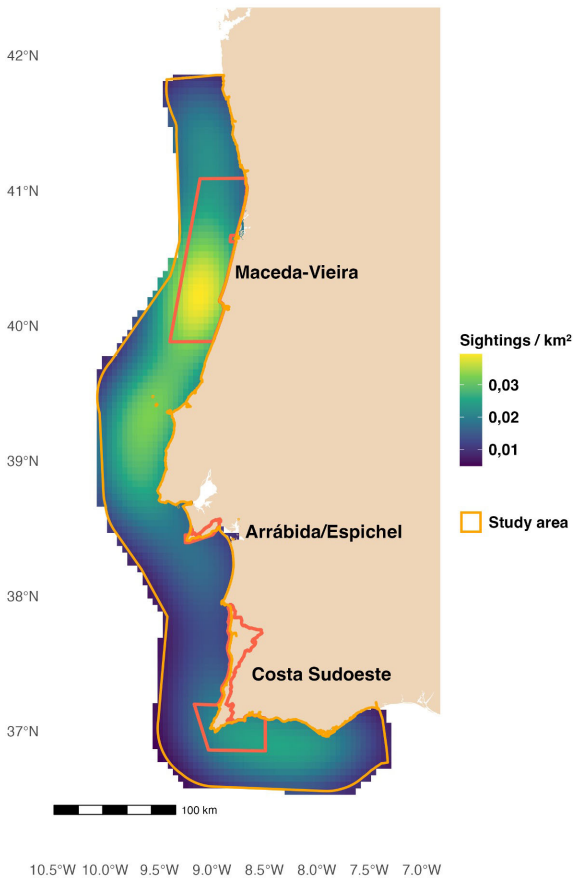


FIGURE 2
Kernel density map of cetacean sightings along the Portuguese coastline between 2004 and 2020. Sightings were aggregated within 5 × 5 km grid cells and smoothed using a 30 km Gaussian kernel to reduce local variability and highlight broader spatial patterns. Map units represent the number of sightings per square kilometer, with warmer colors indicating higher sighting density. Study area boundaries are shown in orange, and protected sites are outlined in red.

2.3 Data analysis

Two metrics of cetacean occurrence were calculated for each cetacean species recorded: the Group Encounter Rate (hereafter, GER) and the Individual Encounter Rate (hereafter, IER), using detectability corrected effort. These metrics were selected as they allow comparisons of cetacean occurrence across space, while accounting for differences in the corrected effort. Specifically, the GER provides information on spatial patterns of species presence and relative distribution, while the IER incorporates group size to reflect relative density or abundance. The GER corresponds to the number of sightings, against the corrected sampling effort (distance travelled in km), per sampling unit. The formula used (Equations 1, 2) was:

$$GER = \frac{s}{E} \quad (1)$$

The IER was calculated as the total number of individuals observed divided by the corrected sampling effort (distance travelled in km), per sampling unit. The formula used was:

$$IER = \frac{i}{E} \quad (2)$$

where:

- s is the total number of sightings for species *x*.
- i is the total number of individuals for species *x*.
- E is the corrected effort (in km).

To facilitate interpretability and standardization, both GER and IER calculations were scaled by a factor of 100, presenting results per 100 km travelled. This standardization ensures that comparisons between protected and non-protected areas are based on effort-corrected encounter rates rather than raw sightings, thereby reducing the influence of unequal survey effort. These calculations were applied both within and outside the three

sites under analysis: Maceda-Praia da Vieira (8,094.64 km), Arrábida (570.70 km), Costa Sudoeste (4,171.53 km), and non-protected areas (28,096.88 km), for a total corrected effort of 40,933.75 km.

Because survey effort and sightings were highly unbalanced among seasons and years, with IPMA campaigns conducted mostly in spring and autumn and opportunistic or dedicated surveys filling spatial gaps irregularly, data from all years and seasons were pooled. Therefore, encounter rates and model outputs should be interpreted as long-term average spatial patterns along the Portuguese coast, rather than as seasonal distributions.

To further examine spatial patterns, the study area was divided into grid squares of 10 × 10 km. This grid size was chosen to balance spatial resolution and data availability, ensuring that each square contained enough survey effort and sightings to allow robust estimation of encounter rates and species richness (Forney et al., 2015; Correia et al., 2019a). Within each grid cell, the corrected effort was aggregated to reflect variation in detectability across the area. Species-specific analyses were conducted within this grid framework for the five most frequently encountered cetacean species, including bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*) Risso's dolphin (*Grampus griseus*), striped dolphin (*Stenella coeruleoalba*), and pilot whale (*Globicephala* spp.). Two species of the genus Globicephala, *Globicephala melas* and *Globicephala macrorynchus*, were initially identified separately during data collection, but were subsequently combined according to the genus (*i.e.*, pilot whale), as both species are almost indistinguishable at-sea. Habitat-fixed variables (habitat-based predictors) were identified and extracted at the centroid of each 10 × 10 km grid cell: distance to coast, distance to canyons, bathymetry and slope, all recognized to be integral factors influencing cetacean biology (Redfern et al., 2006; Moors-Murphy, 2014; Claro et al., 2020). Additionally, the distance from each center of the grid cell to the nearest marine protected zone was included as a spatial-based predictor. Finally, latitude was also considered as a potential geographical predictor. The processing of the variables was conducted under ArcGis Pro (Version 3.2.1). The General Bathymetric Chart of the Oceans (GEBCO) portal provided the bathymetry (15 arc-second resolution) and canyons data (GEBCO Compilation Group, 2020). The slope was derived from bathymetry using the "Spatial Analysis" tool in ArcGIS, with a resolution of 15 arc-seconds. For bathymetry and slope, the "Zonal Statistics" tool was used to calculate minimum, maximum, mean, median, and standard deviation values for each grid cell. Boxplots were generated using R (R Core Team, 2023) within RStudio (Version 2023.03.0 + 386), each corresponding to the variables: distance to coast, distance to canyons, bathymetry, slope, distance to nearest MPA and latitude. For each variable we represent the corresponding distribution for the locations where each of the species was found, as well as the distribution pooled across the five species and the overall distribution sampled while on effort. Five boxes represented the selected species of interest, alongside two additional boxes for the overall species (considering total cetacean sightings) and effort (considering unique effort points). A Kruskal-Wallis test was conducted as an exploratory, non-parametric method to assess significant differences in the range of occurrence across the variables, among the five selected species, the total cetacean sightings, and the effort points. This test served to describe general habitat separation among species, independently from the subsequent GAM modelling. This was followed by a Dunn's test for pairwise multiple comparisons, with p-values adjusted using the Bonferroni method. Species with fewer than 10 observations (*i.e.*, *G. griseus*) were excluded from the Kruskal-Wallis test.

2.4 Statistical modelling

Generalized Additive Models (GAMs) (*e.g.* Wood, 2006) were selected for their flexibility in modelling complex and potentially non-linear relationships between environmental variables and cetacean occurrence. This modelling framework has been extensively applied in marine ecology to explore species–environment relationships, particularly for cetaceans (Redfern et al., 2006; Becker et al., 2010). GAMs were fitted using the grid cells as sampling units for the five selected cetacean species; the corrected effort was included as an offset term to account for differences in sampling intensity among cells. Three separate models were developed to address different ecological questions. The first model only included the bottlenose dolphin and the common dolphin which had sufficient sample sizes to support spatial modelling; the response variable was the total number of sightings per grid cell. The second model used the total number of individuals observed per grid cell to investigate patterns in relative abundance, including all the five selected species. The third model explored species richness by modelling the total number of distinct species identified per grid cell, using the same detectability-corrected effort as an offset to standardize richness estimates across cells with varying survey intensity. Only sightings confirmed at the species level were included in this model, except for pilot whales, which were retained at the genus level (*i.e.*, *Globicephala*). These included the bottlenose dolphin, common dolphin, false killer whale (*Pseudorca crassidens*), fin whale (*Balaenoptera physalus*), harbor porpoise minke whale (*Balaenoptera acutorostrata*), pilot whale (*Globicephala* spp.), Risso's dolphin and striped dolphin. Species richness was included as a complementary metric to sightings and individuals, as it provides additional information on biodiversity patterns and helps identify multispecies hotspots relevant for conservation planning.

All models used the same set of explanatory variables including:

1. MPA Status: indicating whether a cell overlapped an MPA (Maceda-Praia da Vieira SCI, Arrábida MPA, Costa Sudoeste SCI, or Non-protected areas).
2. Proximity to MPAs: distance from the grid cell centroid to the nearest MPA.
3. Habitat Variables: distance to coast, distance to canyons, bathymetry (minimum, maximum, median, mean, and standard deviation), and slope (minimum, maximum, median, mean, and standard deviation).
4. Geographical Variable: latitude of the grid cell centroid.

Predictors were intentionally restricted to static spatial variables to capture long-term average habitat associations and to ensure consistency across the dataset. To mitigate collinearity, Pearson correlations coefficients were calculated among all explanatory variables, using a threshold of 0.75 used to identify highly correlated pairs (Zuur et al., 2010). Bathymetry and slope, identified as strongly correlated, were initially excluded from the model fitting, to avoid discarding potentially relevant variables. Multicollinearity was further assessed using the Variance Inflation Factor (VIF) with a threshold of 3 (Correia et al., 2020, Correia et al., 2021; Zuur et al., 2010). Generalized Additive Models (GAMs) were fitted using the "mgcv" package (Wood, 2011), with the basis dimension of splines capped at four to prevent overfitting and corresponding ecologically unrealistic smooths (Correia et al., 2021). A Poisson distribution was used for count data and overdispersion was evaluated (Payne et al., 2018); if detected ($\varphi > 1.2$), a negative binomial distribution was employed. Model selection began with a backward selection process based on Akaike Information Criterion (AIC), applied to the full set of uncorrelated predictors. Models with the lowest AIC were preferred, and if the AIC difference (ΔAIC) was less than 2, an ANOVA chi-square test was conducted to check statistical significance (Zuur et al., 2007; Correia et al., 2020, Correia et al., 2021). In absence of significant differences, the simplest model was retained following the principle of parsimony (Burnham and Anderson, 2002). Starting from the model selected in the first step, alternative representations of bathymetry and slope (*e.g.* minimum, maximum, mean, median, standard deviation) were tested separately using a forward selection approach to assess whether any of them could improve model performance without introducing multicollinearity (Correia et al., 2019b, Correia et al., 2020, Correia et al., 2021). After selecting the most suitable representation for each of the two variables, a second backward selection was conducted to obtain the final model. The final model was verified using diagnostic plots from the "gam.check" function, and influential data points were assessed with Hat values >1 (Zuur et al., 2007). Variables whose splines showed an approximately linear trend were modelled using linear functions. Maps of effort-corrected encounter rates and species richness were produced in R using the ggplot2, sf, and viridis packages (R Core Team, 2023).

3 Results

The study encompassed a total corrected sampling effort of approximately 41,000 km. A total of 1,393 cetacean sightings were recorded during the survey period, including 68 sightings of unidentified or uncertain species (Table 1). The common dolphin (*Delphinus delphis*) was the most frequently encountered species, showing the highest GER and IER across all surveyed areas. In contrast, the bottlenose dolphin (*Tursiops truncatus*) was predominantly observed in non-protected areas, where it exhibited the highest GER and IER values (Tab.1). All other recorded cetacean species, including the striped dolphin (*Stenella coeruleoalba*), the harbor porpoise (*Phocoena phocoena*), and pilot whale (*Globicephala* spp.), were exclusively sighted in non-protected areas. Notably, no cetacean sightings were recorded within the Arrábida MPA, likely due to the very limited observation effort conducted in the area.

3.1 Habitat preferences

The analysis of cetacean sightings revealed distinct habitat preferences among species in relation to bathymetry, slope, distance to canyons, distance to the coast, latitude, and distance to the nearest MPA (Figure 3). The Kruskal-Wallis tests confirmed significant differences among the five selected species for all these variables (See Supplementary Materials S4), indicating that habitat preferences vary across taxa. Dunn's *post-hoc* pairwise comparisons showed that bottlenose dolphins and common dolphins were significantly more frequently observed closer to the coast and to MPAs compared to other taxa. In contrast, striped dolphins were found significantly farther from the coast and MPAs. Pilot whales and Risso's dolphins (*Grampus griseus*) were found in deeper waters and steeper slopes, as indicated by significantly lower bathymetry values and higher slope measurements. Both species were also encountered in areas near submarine canyons, showing significant differences from the other taxa in their proximity to these features. Additionally, latitude showed a significant association with species distribution, with pilot whales and Risso's dolphins frequently found at higher (northern) latitudes and bottlenose dolphin and striped dolphin at lower (southern) latitudes. The Dunn's test confirmed that the observed differences among species were statistically significant for all examined variables, reinforcing that environmental and topographic factors consistently structure cetacean distributions along the Portuguese coast (see Supplementary Materials S4).

3.2 Modelling sightings counts

The number of sightings of bottlenose dolphins showed a significant negative relationship with latitude ($p < 0.05$), indicating a decrease in sightings at higher latitudes. Maximum slope had a significant non-linear effect ($p < 0.05$), characterized by a generally flat pattern with slight undulations along the slope gradient (Figure 4). For common dolphins, latitude, distance to the coast, and maximum slope emerged as significant predictors, explaining 15.7% of the deviance (Figure 5). The relationship between latitude and sighting rates was non-linear ($p < 0.05$), with an increase around 40° latitude followed by a decline at higher latitudes. Distance to the coast also exhibited a strong non-linear effect ($p < 0.05$), with higher sightings observed at intermediate distances from shore. Maximum slope was a significant predictor ($p < 0.05$), and was associated with variation in sighting rates.

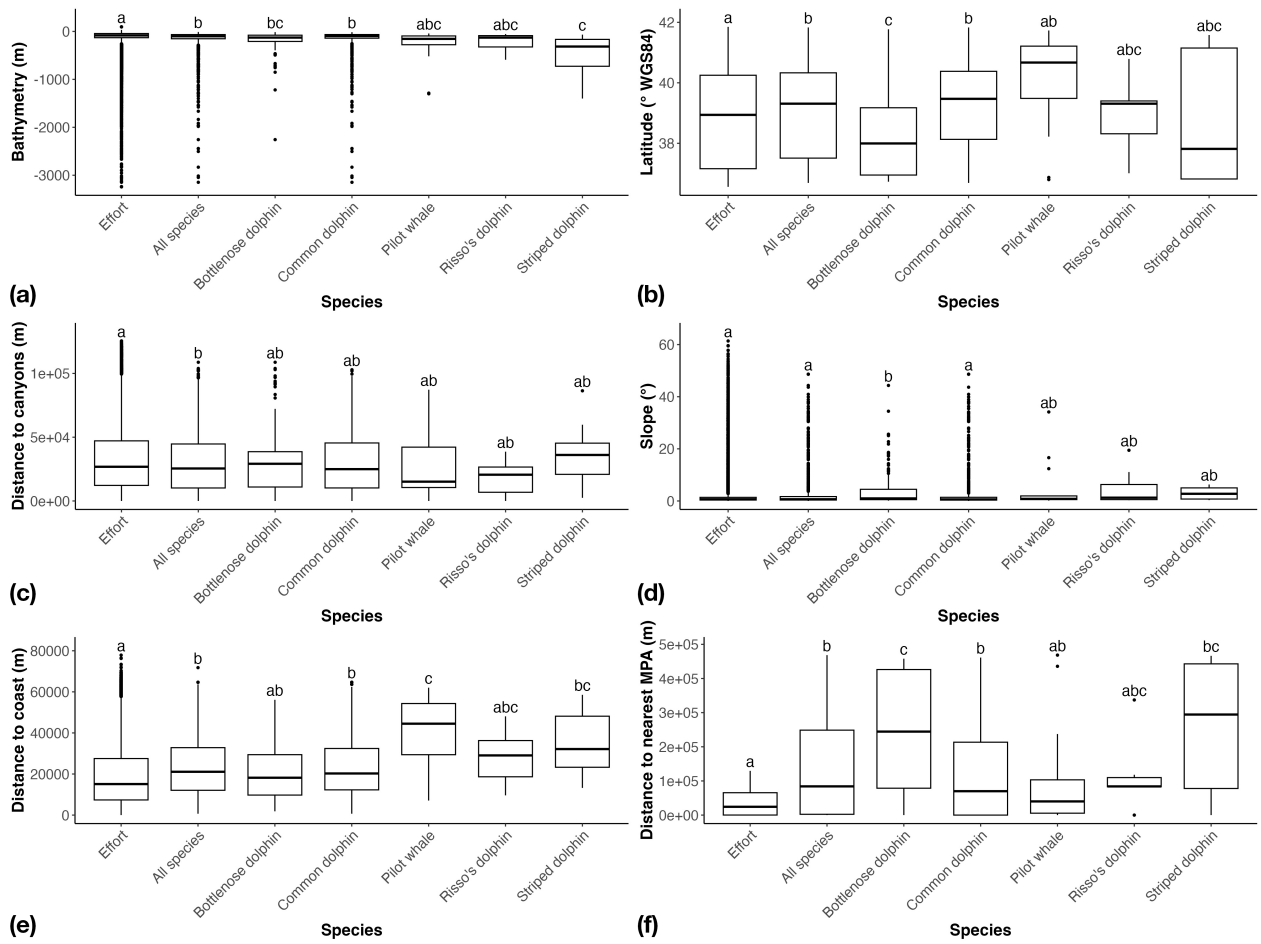


FIGURE 3
Boxplots showing the distribution of six environmental variables for the five selected species: **(A)** bathymetry, **(B)** latitude, **(C)** distance to canyons, **(D)** slope, **(E)** distance to coast, and **(F)** distance to the nearest MPA. The horizontal line within each box represents the median, the box indicates the interquartile range (IQR, 25th–75th percentile), and the whiskers extend up to 1.5 times the IQR. Outliers are shown as individual points. Different letters above boxes indicate statistically significant differences among groups based on Dunn's *post-hoc* tests with Bonferroni correction (see Supplementary Materials S4). Groups sharing at least one letter do not differ significantly.

3.3 Modelling individuals counts

The number of individuals of bottlenose dolphins identified distance to the nearest MPA, distance to the coast, and maximum bathymetry as significant predictors (Figure 6). Distance to the coast exhibited a significant non-linear effect ($p < 0.05$), with encounter rates peaking at intermediate distances. Distance to the nearest MPA showed a weak and marginally significant non-linear effect ($p = 0.05$), with counts decreasing as distance from MPAs increased. Maximum bathymetry had a strong positive effect ($p < 0.05$). The model explained 15% of the deviance. The model for common dolphins identified latitude and distance to the coast as significant predictors (Figure 7). Latitude showed a significant positive effect ($p < 0.05$), indicating an increasing trend at higher (northern) latitudes, while distance to the coast exhibited a strong non-linear relationship, with a peak at intermediate distances ($p < 0.05$). Minimum slope was included in the model but was not statistically significant. The model explained 9.75% of the deviance. For pilot whales, the model identified both latitude and distance to the coast as significant predictors. Latitude had a non-linear effect ($p < 0.05$), while distance to the coast was also highly significant ($p < 0.05$), increasing both at higher latitudes and farther from the coast. The model explained 48.1% of the deviance in the data (Figure 8). For Risso's dolphins, the final model identified maximum slope as the only predictor (Figure 9). However, its effect on the individual aggregation was not statistically significant. The model explained 35.8% of the deviance in the data. Finally the model of striped dolphins identified distance to the coast as the only significant explanatory variable. The relationship was positive and statistically significant ($p < 0.05$), indicating that individuals increased with greater distances from the coast. The model explained 31.9% of the deviance in the data (Figure 10).

3.4 Modelling species richness

The Generalized Additive Model (GAM) for species richness identified distance to the coast and bathymetric variability as

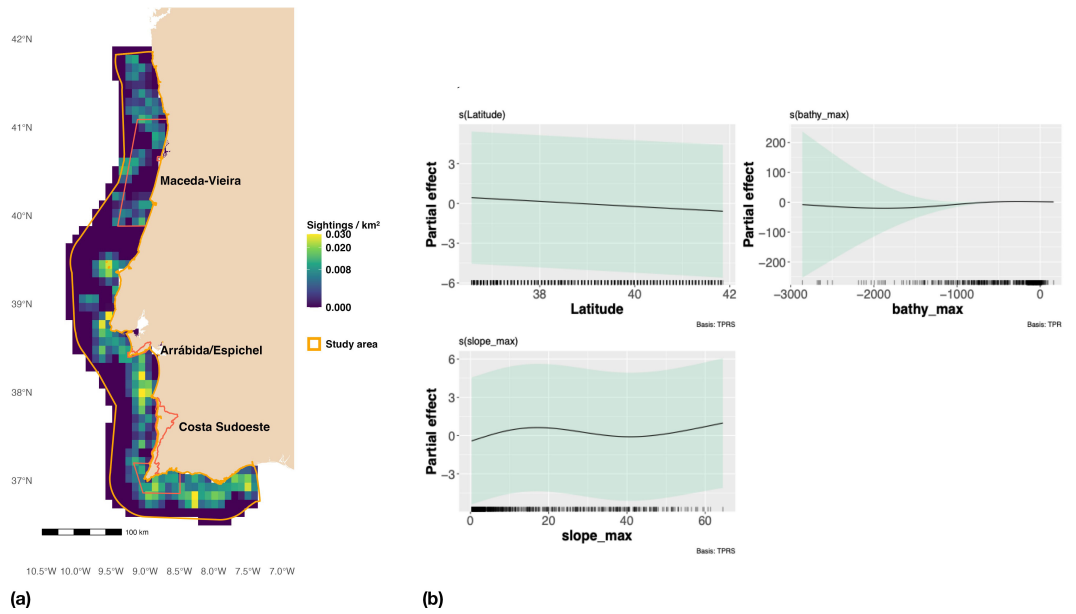


FIGURE 4
(A) Spatial distribution of bottlenose dolphin sightings per km^2, aggregated in 10 × 10 km grid cells across the study area. Marine Protected Areas (MPAs) are outlined in red, and the study area boundary is shown in orange. **(B)** Fitted Generalized Additive Models (GAMs) for bottlenose dolphin sightings. Tick marks above the x-axis indicate the distribution of observations, while the shaded area represents the 95% confidence interval of the spline functions. Variables include: latitude, bathy_max (maximum depth), and slope_max (maximum slope).

significant predictors of the number of species observed per grid cell (Figure 11). Distance to the coast exhibited a strong non-linear relationship ($p < 0.05$), with species richness peaking at intermediate distances from shore. Bathymetric variability showed a significant positive effect ($p < 0.05$). The model explained 14% of the deviance.

4 Discussion

The distribution of cetaceans is shaped by a complex interplay of environmental factors, human activities, and species-specific ecological preferences with environmental variables such as

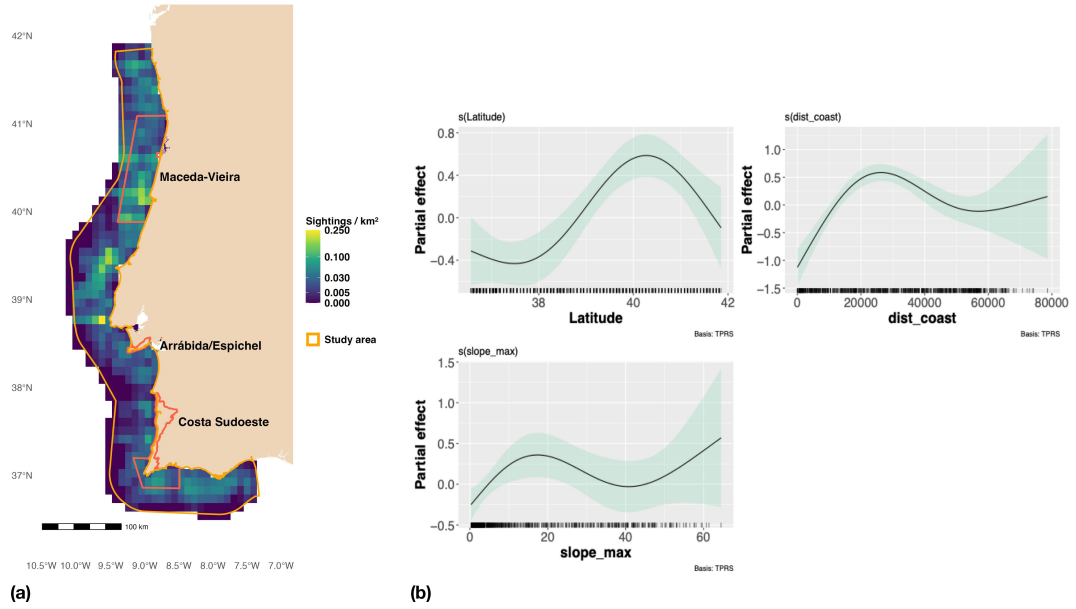


FIGURE 5
(A) Spatial distribution of common dolphin sightings per km^2, aggregated in 10 × 10 km grid cells across the study area. Marine Protected Areas (MPAs) are outlined in red, and the study area boundary is shown in orange. **(B)** Fitted Generalized Additive Models (GAMs) for common dolphin sightings. Tick marks above the x-axis indicate the distribution of observations, while the shaded area represents the 95% confidence interval of the spline functions. Variables include: latitude, dist_coast (distance to the nearest coastline) and slope_max (maximum slope).

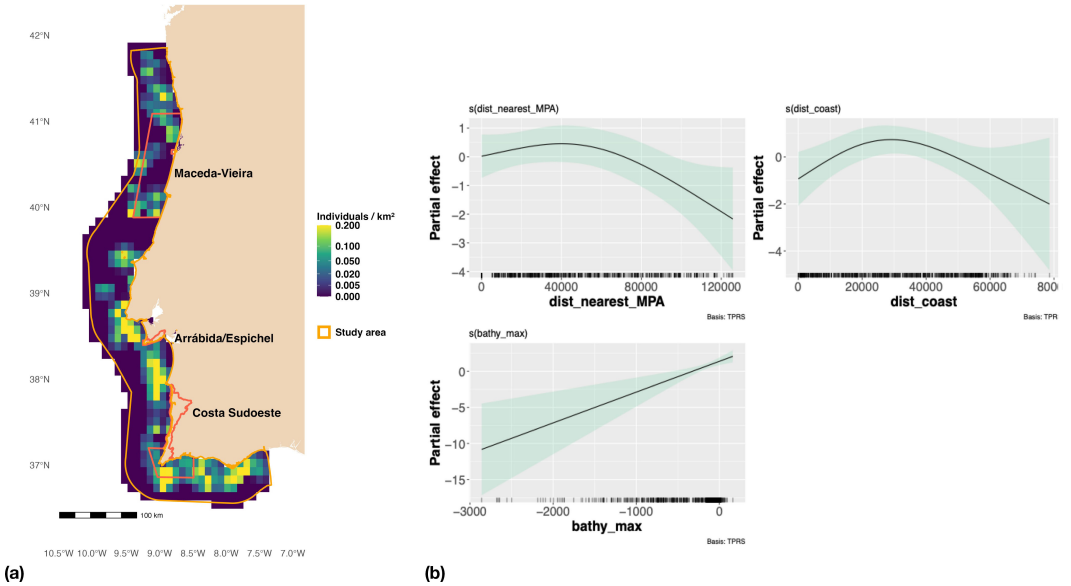


FIGURE 6
(A) Spatial distribution of bottlenose dolphin individuals per km^2, aggregated in 10 × 10 km grid cells across the study area. Marine Protected Areas (MPAs) are outlined in red, and the study area boundary is shown in orange. **(B)** Fitted Generalized Additive Models (GAMs) for bottlenose dolphin individuals. Tick marks above the x-axis indicate the distribution of observations, while the shaded area represents the 95% confidence interval of the spline functions. Variables include: dist_nearest_MPA (distance to the nearest MPA), dist_coast (distance to the nearest coastline) and bathy_max (maximum depth).

depth, slope and canyon proximity acting as widely used proxies for underlying biological processes such as prey availability and foraging opportunities (Forney, 2000; Hastie et al., 2003; Correia et al., 2021). Understanding these patterns is essential for effective conservation planning, particularly in regions with high anthropogenic pressure, such as the Portuguese continental coast. The majority of sightings occurred outside designated MPAs (Table 1), suggesting potential mismatches between current conservation boundaries and species' habitat preferences. For instance, the relatively high encounter rates of common dolphins

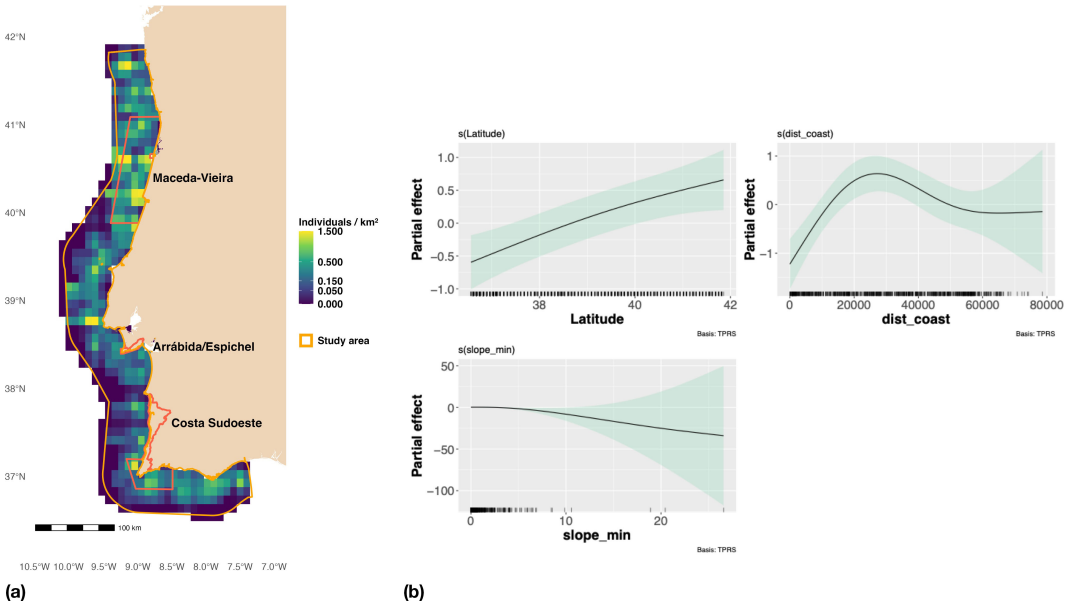


FIGURE 7
(A) Spatial distribution of common dolphin individuals per km^2, aggregated in 10 × 10 km grid cells across the study area. Marine Protected Areas (MPAs) are outlined in red, and the study area boundary is shown in orange. **(B)** Fitted Generalized Additive Models (GAMs) for common dolphin individuals. Tick marks above the x-axis indicate the distribution of observations, while the shaded area represents the 95% confidence interval of the spline functions. Variables include: latitude, dist_coast (distance to the nearest coastline) and slope_min (minimum slope).

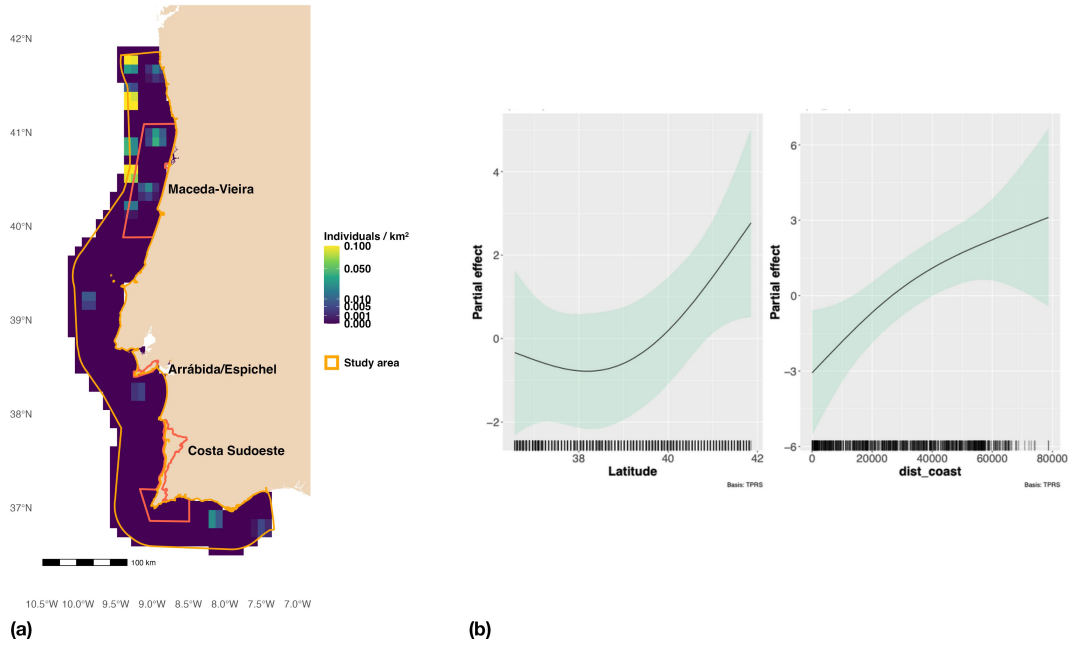


FIGURE 8
(A) Spatial distribution of pilot whale individuals per km^2, aggregated in 10 × 10 km grid cells across the study area. Marine Protected Areas (MPAs) are outlined in red, and the study area boundary is shown in orange. **(B)** Fitted Generalized Additive Models (GAMs) for pilot whale individuals. Tick marks above the x-axis indicate the distribution of observations, while the shaded area represents the 95% confidence interval of the spline functions. Variables include: latitude and dist_coast (distance to the nearest coastline).

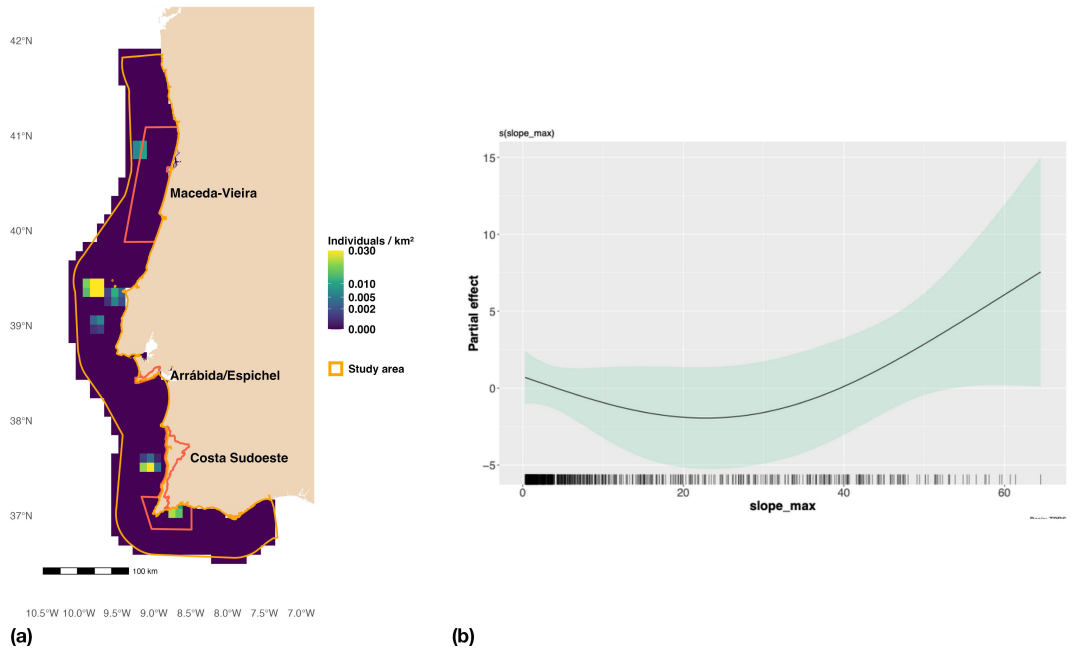


FIGURE 9
(A) Spatial distribution of Risso's dolphin individuals per km^2, aggregated in 10 × 10 km grid cells across the study area. Marine Protected Areas (MPAs) are outlined in red, and the study area boundary is shown in orange. **(B)** Fitted Generalized Additive Models (GAMs) for Risso's dolphin individuals. Tick marks above the x-axis indicate the distribution of observations, while the shaded area represents the 95% confidence interval of the spline functions. Variables include: slope_max (maximum slope).

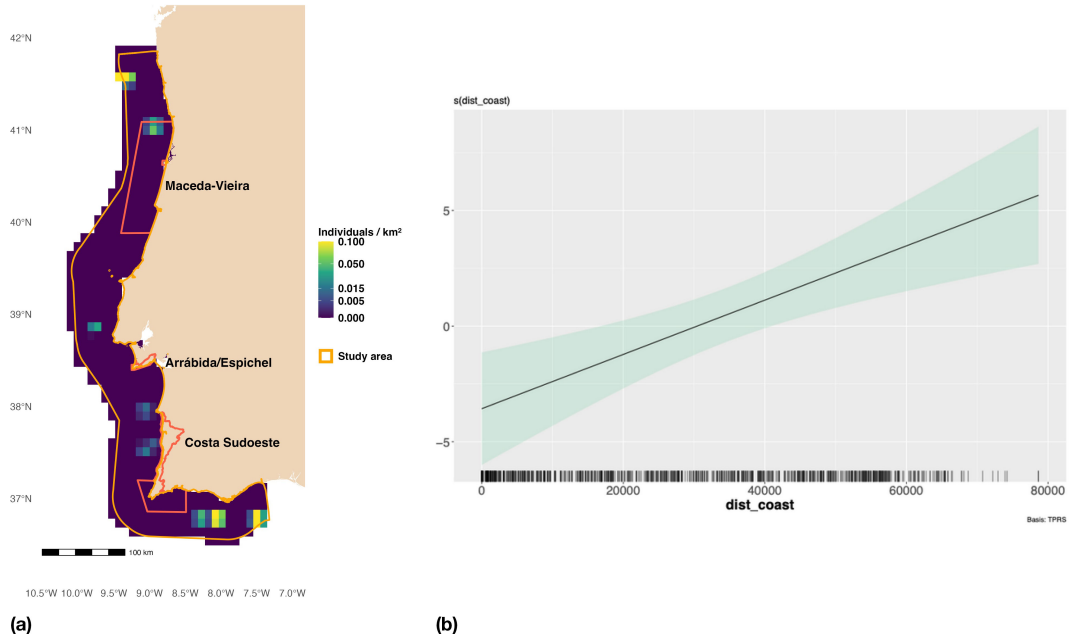


FIGURE 10
(A) Spatial distribution of striped dolphin individuals per km^2, aggregated in 10 × 10 km grid cells across the study area. Marine Protected Areas (MPAs) are outlined in red, and the study area boundary is shown in orange. **(B)** Fitted Generalized Additive Models (GAMs) for striped dolphin individuals. Tick marks above the x-axis indicate the distribution of observations, while the shaded area represents the 95% confidence interval of the spline functions. Variables include: dist_coast (distance to the nearest coastline).

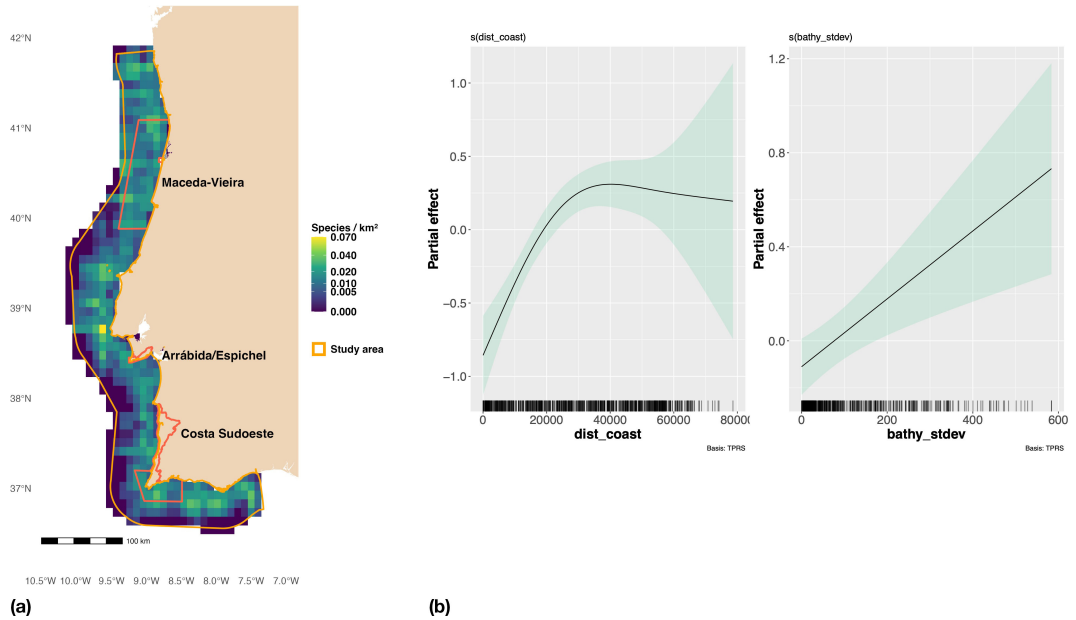


FIGURE 11
(A) Spatial distribution of species richness per km^2, aggregated in 10 × 10 km grid cells across the study area. Marine Protected Areas (MPAs) are outlined in red, and the study area boundary is shown in orange. **(B)** Fitted Generalized Additive Models (GAMs) for species richness. Tick marks above the x-axis indicate the distribution of observations, while the shaded area represents the 95% confidence interval of the spline functions. Variables include: dist_coast (distance to the nearest coastline) and bathy_stdev (standard deviation of depth).

10.3389/fmars.2025.1706011

TABLE 1 Distribution and abundance of cetacean species across the contiguous zone of Mainland Portugal from 2004 to 2020.

Species	Sightings group encounter rate (GER)					Individuals individual encounter rate (IER)				
	Total	NPA	MCD	ARB	CSW	Tot	NPA	MCD	ARB	CSW
Beaked whale	2 <0.01	2 <0.01	0	0	0	2 <0.01	2 <0.01	0	0	0
Bottlenose dolphin (*Tursiops truncatus*)	156 0.01	125 0.44	16 0.19	0	15 0.35	1,679 4.1	1,378 0.04	144 1.77	0	15 3.76
Common dolphin (*Delphinus delphis*)	1,093 2.67	756 2.7	274 3.38	0	63 1.5	10,754 26.27	7,417 2.4	2,753 34	0	584 13.99
Common/Striped dolphin	5 0.01	4 0.01	1 0.01	0	0	32 0.07	12 0.04	20 0.24	0	0
False killer whale (*Pseudorca crassidens*)	1 <0.01	1 <0.01	0	0	0	12 0.02	12 0.04	0	0	0
Fin whale (*Balaenoptera physalus*)	2 <0.01	2 <0.01	0	0	0	9 0.02	9 0.03	0	0	0
Harbor porpoise (*Phocoena phocoena*)	6 0.01	3 0.01	2 0.02	0	1 0.02	15 0.03	7 0.02	5 0.06	0	3 0.07
Large whale	1 <0.01	1 <0.01	0	0	0	1 <0.01	1 <0.01	0	0	0
Pilot whale (*Globicephala* spp.)	14 0.03	11 0.03	3 0.02	0	0	151 0.36	137 0.48	14 0.17	0	0
Minke whale (*Balaenoptera acutorostrata*)	15 0.03	12 0.04	2 0.02	0	1 0.02	15 0.03	12 0.04	2 0.02	0	1 0.02
Risso's dolphin (*Grampus griseus*)	7 0.01	5 0.01	1 0.01	0	1 0.02	48 0.11	39 0.13	3 0.03	0	6 0.14
Small whale	1 <0.01	1 <0.01	0	0	0	1 <0.01	1 <0.01	0	0	0
Striped dolphin (*Stenella coeruleoalba*)	12 0.02	11 0.03	1 0.1	0	0	118 0.28	108 0.38	10 0.12	0	0
Unidentified dolphin	52 0.12	42 0.14	8 0.38	0	2 0.04	351 0.85	302 1.07	43 0.53	0	6 0.14
Whale or dolphin	17 0.04	11 0.03	6 0.02	0	0	41 0.1	28 0.09	13 0.16	0	0
Whale	9 0.02	9 0.03	0	0	0	26 0.06	26 0.09	0	0	0
Total	1,393 3.40	996 3.54	314 3.87	0	83 1.98	13,255 32.38	9,491 33.77	3,007 37.1	0	757 1.84

For each cell, the top number represents the total number of sightings or individuals, and the number below indicates the group or individual encounter rate.
Reports the total number of sightings and GER (per 100 km surveyed), the total number of individuals and IER (per 100 km surveyed) observed within Non-protected areas (NPA), Maceda-Praia da Vieira protected area (MCD), Arrábida protected area (ARB) and Costa Sudoeste protected area (CSW).

(*Delphinus delphis*) within the Maceda-Praia da Vieira SCI suggest that this site, despite not being designated specifically for their protection, may provide favorable habitat conditions to them. In contrast, bottlenose dolphins (*Tursiops truncatus*) were more frequently observed in non-protected areas, suggesting that existing conservation measures may not encompass their preferred habitats. While cetaceans are inherently mobile and utilize vast areas, these patterns highlight potential gaps in current protection efforts that may need further examination. Additionally, the complete absence of sightings in the Arrábida MPA is most likely attributable to the very limited survey effort in this area, rather than a true absence of cetaceans. Given the known presence of both resident and transient dolphin populations in these waters (Martinho, 2012), further research is needed to assess whether habitat degradation, prey availability, or human activities are influencing their presence in this area.

4.1 Spatial distribution of the five selected species

The five selected cetacean species showed distinct spatial patterns, consistent with their diverse ecological niches. The GAM models provide key insights into these patterns. Modelling

the total number of sightings highlights overall distribution trends, whereas modelling the total number of individuals reveals clustering and aggregation tendencies within species. Combined, these complementary metrics provide a comprehensive perspective on both the spatial occurrence of species and the aggregation behavior of individuals, offering a multifaceted understanding of their distribution.

The sightings model for bottlenose dolphins (Figure 4) revealed a higher presence in southern latitudes and areas with marked slope variability, while the individuals model (Figure 6) highlighted a significant aggregation at intermediate distances from the coast and in deeper waters. Nevertheless, the interpretative strength of these patterns is constrained by the low deviance explained by the models and the limited amplitude of the smooth terms. Rather than indicating clear habitat preferences, the observed associations suggest that bottlenose dolphins may use a range of environmental conditions, potentially influenced by multiple interacting factors not fully captured by the models. Such findings are consistent with previous studies that reported this species in both coastal zones (Gómez De Segura et al., 2006; Carwardine, 2020) and over the continental shelf (Notarbartolo Di Sciara et al., 1993; Bearzi et al., 2004, Bearzi et al., 2009). Additionally, the significant effect of proximity to MPAs on individual encounter rates, particularly in the southern region encompassing the Costa Sudoeste SCI, suggests that this protected area may function as an important aggregation site for bottlenose dolphins. However, this marginal statistical signal ($p = 0.05$) should be interpreted with caution given the limited explanatory power of the model. The conservation implications of this spatial overlap are further discussed in the following section. Common dolphins exhibited a wide distribution across the study area, with both final models identifying significant relationships with latitude, distance to the coast, and seafloor slope (Figures 5, 7). The total number of sightings and individuals was higher at intermediate distances from the coast and in areas with moderate slope, while the non-linear relationship with latitude indicated a preference for northern regions. This flexible habitat use is well documented in previous studies, where *D. delphis* has been recorded in both coastal and offshore environments (Cañadas and Hammond, 2008; Moura et al., 2012; Correia et al., 2019a). The observed preference for mid-shelf northern waters could reflect the presence of productive foraging zones, such as upwelling systems or frontal areas (Correia et al., 2015, Goetz et al., 2015), which are common in northern latitudes of the continental shelf of Portugal, due to seasonal wind-driven processes (Fiúza, 1982). These patterns may be shaped by spatial and seasonal variability in oceanographic conditions and prey availability, which can influence both occurrence and group aggregation (Hammond et al., 2013; Marçalo et al., 2018). Their distribution in northern latitudes, aligns with the presence of the Maceda-Praia protected area. The model for pilot whales (*Globicephala* spp.) (Figure 8) identified distance from the coast as an influential variable, with higher number of individuals occurring further offshore. Additionally, the species was more frequently recorded at higher latitudes within the study area, which may suggest a preference for cooler waters and more productive oceanographic conditions. Although no single variable was statistically significant in the GAM outputs, likely due to the limited number of sightings, the spatial distribution observed aligns with previous findings highlighting the association of *Globicephala* spp. with deep-water habitats and submarine canyons. These environments are known to support their deep-diving foraging strategies targeting squid and other mesopelagic prey (Thorne et al., 2017). Risso's dolphin (*Grampus griseus*) was detected less frequently in the study area (Figure 9), limiting the ability of the models to identify statistically significant environmental predictors. Nonetheless, maximum slope was retained in the model, suggesting a potential association with steep underwater features such as canyons. Although not significant, this variable aligns with known ecological preferences of the species, which is often observed foraging in deep waters near complex topographies (Chicote et al., 2023; Martins et al., 2025). Lastly, striped dolphins (*Stenella coeruleoalba*) showed a clear preference for offshore environments (Figure 10). In the model, distance from the coast emerged as the most influential predictor of their distribution. This pattern suggests a clear association with oceanic habitats, consistent with the species' known ecology and foraging strategies (Azzolin et al., 2020; Marçalo et al., 2021).

The observed distribution patterns highlight the ecological relevance of deep-water habitats, which are often overlooked in conservation strategies focused primarily on coastal areas. Our findings suggest that cetacean habitat use is shaped by a combination of environmental factors (including depth, slope, proximity to submarine canyons, and distance from shore) all of which likely influence prey availability and foraging behavior. In addition, broader ecological dynamics such as seasonal movements, social structure, and interspecific differences in foraging strategies further contribute to the spatial variability observed (Forney, 2000; Redfern et al., 2006; Kaschner et al., 2011; Mannocci et al., 2014). Given the species-specific preferences, it is crucial to evaluate whether existing Marine Protected Areas (MPAs) adequately cover the key habitats used by different cetaceans. The following section assesses the degree of overlap between current MPA coverage and the ecological requirements highlighted by our models, and discusses implications for improving conservation planning and management.

4.2 Conservation actions: present and future

The final model identified distance to the coast and bathymetric variability as significant drivers of species richness, highlighting the importance of habitat complexity in shaping cetacean diversity (Figure 11). The non-linear relationship with distance to the coast, with peak diversity at intermediate distances, may reflect an optimal balance where oceanographic conditions and prey

availability support a higher number of species. Likewise, the positive effect of bathymetric variability reinforces the idea that areas with diverse underwater topography create ecological niches that host multiple cetacean species. By linking species' spatial patterns to the ecological functions of these habitats, such as foraging hotspots, areas of prey concentration or deep-diving grounds, we can better assess whether existing MPAs encompass biologically meaningful areas for cetacean populations.

By comparing the predicted spatial patterns of total sightings and individual aggregations, we found that many key habitats fall outside the boundaries of existing coastal MPAs. For instance, bottlenose dolphins showed high individual aggregation in the proximity of the Costa Sudoeste SCI, and notably, the MPA variable was a significant predictor in their model — the only species for which this occurred. However, despite this spatial association, most of their predicted habitat use falls outside the current boundaries of the MPA. Moreover, the Costa Sudoeste SCI still lacks an approved management plan, which further undermines its potential contribution to bottlenose dolphin conservation. This highlights a critical gap between spatial designation and effective protection, reinforcing the need to ensure that protected sites are not only ecologically relevant but also actively managed and enforced. In contrast to bottlenose dolphins, common dolphins were frequently recorded within the Maceda–Praia da Vieira SCI, indicating a partial spatial overlap with existing protected areas. This suggests that, although not initially targeted by conservation measures in this site, the inclusion of this species in future management objectives could enhance the relevance and effectiveness of the MPA. Such an update would be particularly timely given the recent reclassification of *D. delphis* as near-threatened (Moura et al., 2019), which calls for greater attention to its conservation needs.

Coastal MPAs present key limitations for species with predominantly oceanic distributions, such as striped dolphins, Risso's dolphins, and pilot whales. These species are less likely to benefit from coastal MPAs, as their ecological needs are more aligned with deeper, offshore environments that fall outside the boundaries of most current protected areas.

Insufficient data on harbor porpoise prevented a species-specific analysis in our study. However, given their near-threatened status (Moura et al., 2019) and the ecological significance of this species, future studies should prioritize gathering more comprehensive data to assess their distribution and habitat use. Beyond the mere presence of MPAs, species encounters and MPA effectiveness may be shaped by ecological and environmental factors that are not adequately addressed by current conservation efforts (Notarbartolo Di Sciara, 2008). The Important Marine Mammal Areas (IMMAs) framework may offer a more nuanced and scientifically rigorous approach to cetacean conservation, recognizing the complexity of marine mammal habitats (Tetley et al., 2022). Unlike traditional MPA guidelines, IMMAs criteria are based on biological, ecological, and behavioral factors critical for species survival, such as areas crucial for mating, birthing, foraging, or migration routes. Incorporating these criteria would likely improve the effectiveness of protected areas for the purpose of cetacean conservation. Cetaceans are highly mobile species therefore, scaling up from small, isolated and static MPAs to larger, interconnected networks is essential (Geijer and Jones, 2015). This approach could offer more holistic protection by ensuring that key habitats —both coastal and offshore—are adequately covered. The IMMA framework, combined with existing Natura 2000 sites and MPAs, should be seen as complementary, forming an integrated conservation network that better reflects the complex spatial distribution patterns of cetacean species. Future research should focus on refining our understanding of species-specific habitat use and the environmental variables driving cetacean presence, particularly for less-studied species. Additionally, it is essential to account for the predicted drastic changes in habitat due to climate change, which may alter oceanographic conditions, prey distribution, and the availability of key habitats (Thompson et al., 2023). Understanding these shifts will be crucial for developing adaptive measures that ensure the protection of cetaceans in a rapidly changing marine environment (Kebke et al., 2022). By enhancing our knowledge of how these species interact with their environment, we can better inform conservation strategies that are both comprehensive and adaptable to the dynamic nature of marine ecosystems. Ultimately, this integrated approach will be critical for ensuring the long-term protection and recovery of cetacean populations across diverse marine habitats.

4.3 Study limitations

While this study enhances our understanding of cetacean distribution patterns along the Portuguese coast, certain limitations must be acknowledged when interpreting the results.

A primary limitation is the reliance on encounter rates rather than density estimates. Density-based analyses provide a more robust representation of species distribution by accounting for variations in survey effort and detection probability (Buckland et al., 2001). However, the data required to implement such analyses are not available for most species considered in this study. Another important limitation concerns the spatial coverage of the surveys. Some areas, such as Arrábida, have a very narrow sea extent and were only partially or rarely crossed by survey transects. This limited coverage could explain the absence of sightings in certain regions, rather than indicating an actual absence of cetaceans. Alternative datasets, such as aerial surveys (*e.g.* SCANS), could provide further insights into the presence of cetaceans in these under-sampled areas (Redfern et al., 2006). Additionally, the data were aggregated across multiple years and seasons to increase sample size and improve model stability. While this approach allows for a broader spatial assessment, it may have masked temporal variations in species distribution, particularly seasonal shifts driven by oceanographic conditions and prey availability. By pooling data across multiple years and seasons,

our models capture broad-scale spatial patterns of occurrence but cannot resolve intra-annual (seasonal) shifts that may reflect migration, breeding behavior, or short-term changes in prey availability (Forney, 2000). This limits the interpretation of species–habitat associations in relation to life-cycle stages and hampers the identification of season-specific conservation needs. Addressing this limitation would require surveys designed with consistent seasonal coverage and the integration of temporally dynamic environmental variables (e.g. chlorophyll-a, sea surface temperature, salinity), enabling explicit modelling of seasonal habitat use.

Moreover, the analysis also overlooks inter-annual variability, which may be particularly relevant in long-term datasets (Mannocci et al., 2014). In addition, the absence of seasonally dynamic environmental variables in the models may have affected predictive accuracy. Incorporating variables such as primary production could improve the ability to detect seasonal trends and refine predictions (Virgili et al., 2024). Lastly, the models did not incorporate explicit anthropogenic pressures (*e.g.* fishing activity, maritime traffic) which may influence cetacean distribution at finer spatial and temporal scales (Pirotta et al., 2015).

5 Conclusion

This study provided insights into the habitat preferences and distribution patterns of various cetacean species along the Portuguese coast. By identifying key environmental variables driving their distribution, we have gained a deeper understanding of the spatial dynamics that influence cetacean distribution and habitat use. Moreover, our findings underscore the limitations of the current spatial-based management strategies, particularly the use of MPAs that may not fully encompass the ecological requirements of cetacean species. The concept of IMMAs, which considers a wider range of ecological and behavioral factors, may offer a more effective framework for cetacean conservation. Integrating IMMAs into existing conservation policies could help create a more adaptive and comprehensive network of protected areas, addressing both the habitat preferences of individual species and broader ecosystem-level dynamics. Overall, this research emphasizes the importance of continued monitoring and adaptive spatial-based management that aligns conservation efforts with the dynamic nature of cetacean habitats. By moving beyond static protection measures and incorporating more flexible, data-driven strategies, we can better protect cetacean populations and their ecosystems in the face of ongoing environmental changes and human impacts.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to nuno.oliveira@spea.pt.

Ethics statement

Ethical review and approval was not required for this study because it was based exclusively on non-invasive visual surveys of free-ranging cetaceans. No animals were captured, handled, or experimentally manipulated.

Author contributions

CA: Data curation, Formal Analysis, Visualization, Writing – original draft, Writing – review & editing. DS: Supervision, Writing – review & editing. AC: Formal Analysis, Methodology, Project administration, Supervision, Validation, Writing – review & editing. NO: Investigation, Methodology, Writing – review & editing. TM: Methodology, Software, Supervision, Validation, Visualization, Writing – review & editing.

Funding

The author(s) declared that financial support was received for this work and/or its publication. This research was funded by national funds through FCT – Fundação para a Ciência e a Tecnologia within the scope of the Strategic Funding UIDB/04423/2020 (https://doi.org/10.54499/UIDB/04423/2020), UIDP/04423/2020 (https://doi.org/10.54499/UIDP/04423/2020) and LA/P/0101/2020 (https://doi.org/10.54499/LA/P/0101/2020). TM's work is partially funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under CEAUL Research Unit, UID/00006/2025, DOI: https://doi.org/10.54499/UID/00006/2025.

Acknowledgments

We would like to acknowledge the access to this dataset, which was made possible by the dedicated efforts of a large number of observers operating under the guidance of the Sociedade Portuguesa para o Estudo das Aves (SPEA). Most of the data collection was performed in the aim of several projects co-funded through the LIFE Programme – a funding instrument for the environment and climate action. Special thanks to Claudia Rodrigues, Ágatha Gil, Luís Afonso, and Raul Valente from the Universidade do Porto, CIIMAR, for their invaluable contributions. The present work is part of Camilla Aiuti's Master's thesis.

Conflict of interest

The authors declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Correction note

A correction has been made to this article. Details can be found at: 10.3389/fmars.2026.1822427.

Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2025.1706011/full#supplementary-material.

References

Ângelo, A. (2020). *Arrojamentos de cetáceos e interações com as pescas na costa norte de Portugal Continental* (Aveiro, PT: Universidade de Aveiro).

Azzolin, M., Arcangeli, A., Cipriano, G., Crosti, R., Maglietta, R., Pietroluongo, G., et al. (2020). Spatial distribution modelling of striped dolphin (*Stenella coeruleoalba*) at different geographical scales within the EU Adriatic and Ionian Sea Region, central-eastern Mediterranean Sea. *Aquat. Conserv.: Mar. Freshw. Ecosyst.* 30, 1194–1207. doi: 10.1002/aqc.3314

Bearzi, G., Fortuna, C. M., and Reeves, R. R. (2009). Ecology and conservation of common bottlenose dolphins Tursiops truncatus in the Mediterranean Sea. *Mammal. Rev.* 39, 92–123. doi: 10.1111/j.1365-2907.2008.00133.x

Bearzi, G., Holcer, D., and Notarbartolo di Sciara, G. (2004). The role of historical dolphin takes and habitat degradation in shaping the present status of northern Adriatic cetaceans. *Aquatic. Conserv.: Mar. Freshw. Ecosyst.* 14, 363–379. doi: 10.1002/aqc.626

Bearzi, G., Politi, E., Agazzi, S., and Azzellino, A. (2006). Prey depletion caused by overfishing and the decline of marine megafauna in eastern Ionian Sea coastal waters (central Mediterranean). *Biol. Conserv.* 127, 372–382. doi: 10.1016/j.biocon.2005.08.017

Becker, E. A., Carretta, J. V., Forney, K. A., Barlow, J., Brodie, S., Hoopes, R., et al. (2020). Performance evaluation of cetacean species distribution models developed using generalized additive models and boosted regression trees. *Ecol. Evol.* 12, 5759–5784. doi: 10.1002/ece3.6316

Becker, E. A., Forney, K. A., Ferguson, M., Foley, D., Smith, R., Barlow, J., et al. (2010). Comparing California Current cetacean-habitat models developed using in *situ* and remotely sensed sea surface temperature data. *Mar. Ecol. Prog. Ser.* 413, 163–183. doi: 10.3354/meps08696

Braulik, G. T., Kasuga, M., Wittich, A., Kiszka, J. J., MacCaulay, J., Gillespie, D., et al. (2018). Cetacean rapid assessment: An approach to fill knowledge gaps and target conservation across large data deficient areas. *Aquatic. Conserv: Mar. Freshw. Ecosyst.* 28, 216–230. doi: 10.1002/aqc.2833

Buckland, S. T., Anderson, D. R., Burnham, K. P., and Laake, Jl. (2001). *Introduction to Distance Sampling: Estimating Abundance of Biological Populations* (Oxford: Oxford University Press).

Burnham, K., and Anderson, D. (2002). *Model selection and multi-model inference: A Practical Information-Theoretic Approach 2nd ed* (New York: Springer).

Cañadas, A., and Hammond, P. S. (2008). Abundance and habitat preferences of the short-beaked common dolphin (*Delphinus delphis*) in the Mediterranean Sea. *Endang. Species. Res.* 4, 309–331. doi: 10.3354/esr00073

Cañadas, A., Sagarminaga, R., De Stephanis, R., Urquiola, E., and Hammond, P. S. (2005). Habitat preference modelling as a conservation tool: proposals for marine protected areas for cetaceans in southern Spanish waters. *Aquatic. Conserv: Mar. Freshw. Ecosyst.* 15, 495–521. doi: 10.1002/aqc.689

Carvalho, F. L. (2018). *Arrojamentos de cetáceos ao longo da costa do Algarve: Causas de morte e ensaios piloto de mitigaçãocom alarmes acústicos em pescarias costeiras algarvias* (Faro (PT: Universidade do Algarve).

Carwardine, M. (2020). *Handbook of Whales, Dolphins and Porpoises of the World* (Princeton, NJ: Princeton University Press).

Cheney, B., Corkrey, R., Durban, J., Grellier, K., Hammond, P. S., Islas-Villanueva, V., et al. (2014). Long-term trends in the use of a protected area by small cetaceans in relation to changes in population status. *Glob. Ecol. Conserv.* 2, 118–128. doi: 10.1016/j.gecco.2014.08.010

Chicote, C. A., Amigó, N., and Gazo, M. (2023). Submarine canyons as key habitats to preserve Risso's dolphin *(Grampus griseus)* population in the northwestern Mediterranean Sea. *Front. Mar. Sci.* 10. doi: 10.3389/fmars.2023.1080386

Claro, B., Pérez-Jorge, S., and Frey, S. (2020). Seafloor geomorphic features as an alternative approach into modelling the distribution of cetaceans. *Ecol. Inform* 58, 101092. doi: 10.1016/j.ecoinf.2020.101092

Correia, A. M., Gandra, M., Liberal, M., Valente, R., Gil, Á, Rosso, M., et al. (2019b). A dataset of cetacean occurrences in the Eastern North Atlantic. *Sci. Data* 6, 17. doi: 10.1038/s41597-019-0187-2

Correia, A. M., Gil, Á, Valente, R., Rosso, M., Pierce, G. J., and Sousa-Pinto, I. (2019a). Distribution and habitat modelling of common dolphins (*Delphinus delphis*) in the eastern North Atlantic. *J. Mar. Biol. Assoc. UK.* 99, 1443–1457. doi: 10.1017/S0025315419000249

Correia, A. M., Gil, Á, Valente, R. F., Rosso, M., Sousa-Pinto, I., and Pierce, G. J. (2020). Distribution of cetacean species at a large scale-Connecting continents with the Macaronesian archipelagos in the eastern North Atlantic. *Divers. Distrib.* 26, 1234–1247. doi: 10.1111/ddi.13127

Correia, A. M., Sousa-Guedes, D., Gil, Á, Valente, R., Rosso, M., Sousa-Pinto, I., et al. (2021). Predicting cetacean distributions in the eastern North Atlantic to support marine management. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.643569

Correia, A. M., Tepsich, P., Rosso, M., Caldeira, R., and Sousa-Pinto, I. (2015). Cetacean occurrence and spatial distribution: Habitat modelling for offshore waters in the Portuguese EEZ (NE Atlantic). *Journal of Marine Systems* 143, 73–85. doi: 10.1016/j.jmarsys.2014.10.016

Council of the European Communities (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. *Off. J. Eur. Comm. L.* 206, 7–50.

Edgar, G. J., Stuart-Smith, R. D., Willis, T. J., Kininmonth, S., Baker, S. C., Banks, S., et al. (2014). Global conservation outcomes depend on marine protected areas with five key features. *Nature* 506, 216–220. doi: 10.1038/nature13022

Erbe, C., Marley, S. A., Schoeman, R. P., Smith, J. N., Trigg, L. E., and Embling, C. B. (2019). The Effects of ship noise on marine mammals-A review. *Front. Mar. Sci.* 6. doi: 10.3389/fmars.2019.00606

European Commission (2001). *Natura 2000 Standard Data Form: Sites of Community Importance for Maceda-Praia da Vieira, Arrábida and Costa Sudoeste (PTCON0063, PTCON0010, PTCON0012)* (Brussels: European Commission). Available online at: https://natura2000.eea.europa.eu/.

European Environment Agency (EEA) *Spatial Analysis of Marine Protected Area Networks in Europe's Seas III. ETC/ICM Technical Report 3/2020: European Topic Centre on Inland, Coastal and Marine Waters*. Available online at: https://www.eionet.europa.eu/etcs/etc-icm/products/etc-icm-reports/etc-icm-report-3-2020-spatial-analysis-of-marine-protected-area-networks-in-europe2019s-seas-iii (Accessed May 5, 2025).

Evans, P. G. H., and Hammond, P. S. (2004). Monitoring cetaceans in european waters mammal. *Rev* 34, 131–156. doi: 10.1046/j.0305-1838.2003.00027.x

Farmer, N. A., Baker, K., Zeddies, D. G., Denes, S. L., Noren, D. P., Garrison, L. P., et al. (2018). Population consequences of disturbance by offshore oil and gas activity for

endangered sperm whales (*Physeter macrocephalus*). *Biol. Conserv.* 227, 189–204. doi: 10.1016/j.biocon.2018.09.006

Ferreira, M. (2007). *Ocorrência e captura acidental de cetáceos no Centro/Norte de Portugal* (Braga (PT: Universidade do Minho).

Ferreira, M., Marçalo, A., Nicolau, L., Pereira, A., Costa, E., and Vingada, J. (2016). "Redes de arrojamentos e reabilitação de animaismarinhos," in *Anexo ao 4° relatório de progresso do projectoLIFE MarPro NAT/PT/0038* (Projecto LIFE MarPro, Portugal).

Fiúza, A. F. G. (1982). "Upwelling patterns off Portugal," in *Coastal Upwelling: Its Sediment Record. NATO Conference Series*, vol. 10 . Eds. E. Suess and J. Thiede (Springer, Boston, MA).

Forney, K. A. (2000). Environmental models of cetacean abundance: Reducing uncertainty in population trends. *Conserv. Biol.* 14, 1271–1286. doi: 10.1046/j.1523-1739.2000.99412.x

Forney, K. A., Becker, E. A., Foley, D. G., and Barlow, J. (2015). Habitat-based models of cetacean density and distribution in the central North Pacific. *Endanger. Species. Res.* 27, 1–20. doi: 10.3354/esr00632

Frazão Santos, C., Orbach, M. K., Calado, H., and Andrade, F. (2015). Challenges in implementing sustainable marine spatial planning: The new Portuguese legal framework case. *Mar. Pol.* 61, 196–206. doi: 10.1016/j.marpol.2015.08.010

GEBCO Compilation Group (2020). *GEBCO_2020 Grid* (NERC, UK: GEBCO Compilation Group). doi: 10.5285/a29c5465-b138-234d-e053-6c86abc040b9

Geijer, C., and Jones, P. J. (2015). A network approach to migratory whale conservation: Are MPAs the way forward or do all roads lead to IMO? *Mar. Policy* 51, 1–12. doi: 10.1016/j.marpol.2014.06.002

Global Fishing Watch (2023). Available online at: https://globalfishingwatch.org/map (Accessed April 20, 2024).

Goetz, S., Read, F. L., Ferreira, M., Portela, J. M., Santos, M. B., Vingada, J., et al. (2015). Cetacean occurrence, habitat preferences and potential for cetacean–fishery interactions in Iberian Atlantic waters: results from cooperative research involving local stakeholders. *Aquatic. Conserv.: Mar. Freshw. Ecosyst.* 25, 138–154. doi: 10.1002/aqc.2481

Gómez De Segura, A., Crespo, E. A., Pedraza, S. N., Hammond, P. S., and Raga, J. A. (2006). Abundance of small cetaceans in waters of the central Spanish Mediterranean. *Mar. Biol.* 150, 149–160. doi: 10.1007/s00227-006-0334-0

Grau,, Tomás, E., García,, and Sanabria, J. (2022). Comparative analysis of marine-protected area effectiveness in the protection of marine mammals: Lessons learned and recommendations. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.940803

Guisan, A., Tingley, R., Baumgartner, J. B., Naujokaitis-Lewis, I., Sutcliffe, P. R., Tulloch, A. I., et al. (2013). Predicting species distributions for conservation decisions. *Ecol. Lett.* 16, 1424–1435. doi: 10.1111/ele.12189

Hammond, P. S., Macleod, K., Berggren, P., Borchers, D. L., Burt, L., Cañadas, A., et al. (2013). Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. *Biol. Conserv.* 164, 107–122. doi: 10.1016/j.biocon.2013.04.010

Hastie, G. D., Wilson, B., Wilson, L., Parsons, K. M., and Thompson, P. M. (2003). Functional mechanisms underlying cetacean distribution patterns: Hotspots for bottlenose dolphins are linked to foraging. *Mar. Biol.* 144, 397–403. doi: 10.1007/s00227-003-1195-4

Horta E Costa, B., Claudet, J., Franco, G., Erzini, K., Caro, A., and Gonçalves, E. J. (2016). A regulation-based classification system for Marine Protected Areas (MPAs). *Mar. Pol.* 72, 192–198. doi: 10.1016/j.marpol.2016.06.021

Horta E Costa, B., De Benito-Abelló, C., Pike, E., Turnbull, J., MacCarthy, J., Harasta, N., et al. (2025). Marine protected areas stage of establishment and level of protection are good predictors of their conservation outcomes. *Cell Rep. Sustain.* 2, 100345. doi: 10.1016/j.crsus.2025.100345

IUCN-MMPATF (2024). *Atlantic Coast of the Iberian Peninsula IMMA Factsheet* (IUCN Joint SSC/WCPA Marine Mammal Protected Areas Task Force). Available online at: https://www.marinemammalhabitat.org/factsheets/atlantic-coast-of-the-iberian-peninsula-imma.

Kaschner, K., Tittensor, D. P., Ready, J., Gerrodette, T., and Worm, B. (2011). Current and future patterns of global marine mammal biodiversity. *PloS One* 6. doi: 10.1371/journal.pone.0019653

Kebke, A., Samarra, F., and Derous, D. (2022). Climate change and cetacean health: impacts and future directions. *Phil. Trans. R. Soc. B.* 377, 20210249. doi: 10.1098/rstb.2021.0249

Klaassen, M., Marques, T. A., Alves, F., and Fernandez, M. (2025). Trends in marine species distribution models: a review of methodological advances and future challenges. *Ecography* 2025, e07702. doi: 10.1002/ecog.07702

Kriegl, M., Elías Ilosvay, X. E., Von Dorrien, C., and Oesterwind, D. (2021). Marine protected areas: at the Crossroads of nature conservation and fisheries management. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.676264

Lewison, R. L., Crowder, L. B., Read, A. J., and Freeman, S. A. (2004). Understanding impacts of fisheries bycatch on marine megafauna. *Trends. Ecol. Evol.* 19, 598–604. doi: 10.1016/j.tree.2004.09.004

Magera, A. M., Flemming, J. M., Kaschner, K., Christensen, L. B., and Lotze, H. K. (2013). Recovery trends in marine mammal populations. *PloS One* 8. doi: 10.1371/journal.pone.0077908

Mannocci, L., Dabin, W., Augeraud-Véron, E., Dupuy, J. F., Barbraud, C., and Ridoux, V. (2014). Predicting cetacean and seabird habitats in the ocean: Identifying priority areas to mitigate human impacts. *Prog. Oceanogr.* 120, 383–398. doi: 10.1016/j.pocean.2013.11.005

Marçalo, A., Katara, I., Feijó, D., Araújo, H., Oliveira, I., Santos, J., et al. (2015). Quantification of interactions between the Portuguese sardine purse-seine fishery and cetaceans. *ICES. J. Mar. Sci.* 72, 2438–2449. doi: 10.1093/icesjms/fsv076

Marçalo, A., Giménez, J., Nicolau, L., Frois, J., Ferreira, M., Sequeira, M., et al. (2021). Stranding patterns and feeding ecology of striped dolphins, *Stenella coeruleoalba*. *Journal of Sea Research*. 169, 101996. doi: 10.1016/j.seares.2021.101996

Marçalo, A., Nicolau, L., Giménez, J., Ferreira, M., Santos, J., Araújo, H., et al. (2018). Feeding ecology of the common dolphin (Delphinus delphis) in Western Iberian waters: has the decline in sardine (Sardina pilchardus) affected dolphin diet? *Mar. Bio* 165, 44. doi: 10.1007/s00227-018-3285-3

Martinho, F. (2012). *Residency and behavioural patterns of coastal bottlenose dolphins (*Tursiops truncatus*) in the Arrábida and Tróia shores (Portugal)* (Lisbon (PT: Universidade de Lisboa).

Martins, M., Matos, F., Cid, A., Estrela, G., Quirin, A., Borges, F., et al. (2025). Habitat preference of Risso's dolphins (*Grampus griseus*) in the south coast of Portugal. *Mar. Mamm. Sci.* 41, e70001. doi: 10.1111/mms.70001

Melo- Merino, S. M., Reyes-Bonilla, H., and Lira-Noriega, A. (2020). Ecological niche models and species distribution models in marine environments: A review and spatial analysis of evidence. *Ecol. Model.* 415, 108837. doi: 10.1016/j.ecolmodel.2019.108837

Moors-Murphy, H. B. (2014). Submarine canyons as important habitat for cetaceans, with special reference to the Gully: A review. *Deep. Sea. Res. II.* 104, 6–19. doi: 10.1016/j.dsr2.2013.12.016

Moura, A., Sillero, N., and Rodrigues, A. (2012). Common dolphin (*Delphinus delphis*) habitat preferences using data from two platforms of opportunity. *Acta Oecol.* 38, 24–32. doi: 10.1016/j.actao.2011.08.006

Moura, A., Silva C, S. P. E. A., Correia, A., Sousa Pinto, I., Gil, A., Freitas, L., et al. (2019). "Mamíferos Marinhos - Atlas de Mamíferos de Portugal, 2ª edição," in *Atlas de Mamíferos de Portugal, 2ª edição*. Eds. J. Bencatel, H. Sabino-Marques, F. Álvares, A. E. Moura and A. M. Barbosa (Universidade de Évora, Portugal), 159–204.

Notarbartolo Di Sciara, G. (2008). "Marine Protected Areas for Cetaceans:basic concepts on selection, creation and management," in *Selection criteria for marine protected areas for cetaceans*. Ed. P. G. H. Evans (Proc 21st Eur Cetacean Soc Annu Conf, European Cetacean Society, Caernafon), 7–13.

Notarbartolo Di Sciara, G., Venturino, M. C., Zanardelli, M., Bearzi, G., Borsani, J. F., and Cavalloni, B. (1993). Cetaceans in the central Mediterranean Sea: distribution and sighting frequencies. *Ital. J. Zool.* 60, 131–138. doi: 10.1080/11250009309355800

OSPAR Commission (1992). *Convention for the Protection of the Marine Environment of the North-East Atlantic*. Available online at: https://www.ospar.org/convention/text (Accessed May 10 2025).

Papastravou, V., Leaper, R., and Lavigne, D. (2017). Why management decisions involving marine mammals should include animal welfare. *Mar. Pol.* 79, 19–24. doi: 10.1016/j.marpol.2017.02.001

Pasanisi, E., Pace, D. S., Orasi, A., Vitale, M., and Arcangeli, A. (2024). A global systematic review of species distribution modelling approach for cetaceans and sea turtles. *Ecol. Inf.* 82, 103700. doi: 10.1016/j.ecoinf.2024.102700

Payne, E. H., Gebregziabher, M., Hardin, J. W., Ramakrishnan, V., and Egede, L. E. (2018). An empirical approach to determine a threshold for assessing overdispersion in Poisson and negative binomial models for count data. *Commun. Stat. Simul. Comput.* 47, 1722–1738. doi: 10.1080/03610918.2017.1323223

Pirotta, E., Merchant, N. D., Thompson, P. M., Barton, T. R., and Lusseau, D. (2015). Quantifying the effect of bat disturbance on bottlenose dolphin foraging activity. *Biol. Conserv.* 181, 82–89. doi: 10.1016/j.biocon.2014.11.003

R Core Team (2023). *R: A Language and Environment for Statistical Computing*_ (Vienna, Austria: R Foundation for Statistical Computing). Available online at: https://www.R-project.org/ (Accessed September 5, 2025).

Redfern, J., Ferguson, M., Becker, E., Hyrenbach, K., Good, C., Barlow, J., et al. (2006). Techniques for cetacean habitat modeling. *Mar. Ecol. Prog. Ser.* 310, 271–295. doi: 10.3354/meps310271

Remili, A., McKinney, M. A., Maldonado-Rodriguez, A., Ferguson, S. H., Caputo, M., and Kiszka, J. J. (2024). Legacy persistent organic pollutants among multiple cetacean species in the Northwest Atlantic. *Sci. Total. Environ.* 954, 176746. doi: 10.1016/j.scitotenv.2024.176746

Rodríguez, Y., Silva, M. A., Pham, C. K., and Duncan, E. M. (2023). Cetaceans playing with single-use plastics (SUPs): A widespread interaction with likely severe impacts. *Mar. pollut. Bull.* 198, 115428. doi: 10.1016/j.marpolbul.2023.115428

Sequeira, M., and Ferreira, C. (1994). Coastal fisheries and cetacean mortality in Portugal, Report of the International Whaling Commission. *Scientia Marina*. 71, 405–12. doi: 10.3989/scimar.2007.71n2405

Tanabe, S. (2002). Contamination and toxic effects of persistent endocrine disrupters in marine mammals and birds. *Mar. pollut. Bull.* 45, 69–77. doi: 10.1016/S0025-326X(02)00175-3

Tasker, M., Jones, P. H., Dixon, T., and Blake, B. F. (1984). Counting seabirds at sea from ships: A review of methods employed and a suggestion for a standardized approach. *Ornithology* 101, 567–577. doi: 10.1093/auk/101.3.567

Tetley, M., Braulik, G. T., Lanfredi, C., Minton, G., Panigada, S., Politi, E., et al. (2022). The Important Marine Mammal Area Network: a tool for systematic spatial planning in response to the marine mammal habitat conservation crisis. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.841789

Thompson, M., Couce, E., Schratzberger, M., and Lynam, C. P. (2023). Climate change affects the distribution of diversity across marine food webs. *Glob. Change Biol.* 29, 6606–6619. doi: 10.1111/gcb.16881

Thorne, L., Foley, H., Baird, R., Webster, D., Swaim, Z., and Read, A. (2017). Movement and foraging behavior of short-finned pilot whales in the Mid-Atlantic Bight: Importance of bathymetric features and implications for management. *Mar. Ecol. Prog. Ser.* 584, 245–257. doi: 10.3354/meps12371

United Nations (1982). *United Nations Convention on the Law of the Sea*. Available online at: https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf (Accessed May 5, 2024).

Vingada, J., Pereira, A., Ferreira, M., Monteiro, S., Costa, E., and Eira, C. (2015). "Implementação de medidas de mitigação em artesde pesca," in *Anexo ao 4º relatório de progresso do projectoLIFE MarPro NAT/PT/0038* (Projecto LIFE MarPro, Portugal).

Virgili, A., Authier, M., Laran, S., Ridoux, V., and Certain, G. (2024). Seasonal distribution of cetaceans in European Atlantic and Mediterranean waters. *Front. Mar. Sci.* 11. doi: 10.3389/fmars.2024.1319791

Wise, L., Silva, A., Ferreira, M., Silva, M. A., and Sequeira, M. (2007). Interactions between small cetaceans and the purse-seine fishery in western Portuguese waters. *Sci. Mar.* 71, 405–412. doi: 10.3989/scimar.2007.71n2405

Wood, S. N. (2006). *Generalized Additive Models: An Introduction with R* (London: Chapman & Hall/CRC).

Wood, S. N. (2011). Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *JR. Stat. Soc (B).* 73, 3–36. doi: 10.1111/j.1467-9868.2010.00749.x

Zantis, L. J., Carroll, E. L., Nelms, S. E., and Bosker, T. (2021). Marine mammals and microplastics: a systematic review and call for standardisation. *Environ. pollut.* 269, 116142. doi: 10.1016/j.envpol.2020.116142

Zuur, A. F., Ieno, E. N., and Elphick, C. S. (2010). A protocol for data exploration to avoid common statistical problems. *Methods Ecol. Evol.* 1, 3–14. doi: 10.1111/j.2041-210X.2009.00001.x

Zuur, A. F., Ieno, E. N., and Smith, G. M. (2007). *Analysing Ecological Data* (New York, NY: Springer).