

Cetacean biodiversity in the Bay of Biscay: Suggestions for environmental protection derived from citizen science data

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ABSTRACT

Cetacean communities face significant threats from adverse interactions with human activities such as bycatch, vessel collision, and environmental pollution. Monitoring of marine mammal populations can help to assess and safeguard marine biodiversity for future generations. Traditional surveys can be costly and time-consuming to undertake, but we explore the ability of citizen science to inform environmental assessments and subsequent conservation management. We use data collected from platforms of opportunity within the Bay of Biscay to investigate spatial changes in cetacean diversity, with the aim of identifying hotspots which may be suitable for further investigation and conservation. Seventeen species of cetaceans were recorded over a ten year period, many of which are data deficient in European waters (e.g. Bottlenose dolphin, Short-beaked common dolphin, Striped dolphin, Risso's dolphin, Long-finned pilot whale, Killer whale, Northern bottlenose whale, Cuvier's beaked whale, Sowerby's beaked whale and True's beaked whale). Biodiversity (determined by Simpson's Diversity index) ranged from 0.19 to 0.77. The central and southern areas of the survey area indicated the highest biodiversity (0.65–0.77), and these locations may benefit most from protection as Important Marine Mammal Areas. We present a case for this designation, and discuss the benefits and limitations of citizen science for informing conservation action.

1. Introduction

Historically, marine mammals have captivated public attention as charismatic megafauna which can inspire individuals to learn about marine ecosystems and promote environmental stewardship [1]. However, despite global efforts to conserve cetaceans, many populations are in decline, or are a small percentage of their historic abundance [2]. Today, cetacean species face a range of threats from human activities including vessel collisions, entrapment in fishing gear (bycatch), ghost gear entanglement, and the impacts of anthropogenic underwater noise [3–6]. These ongoing pressures highlight the need to improve existing conservation mechanisms, strengthen their implementation and compliance, and develop new policies which responds to the challenges posed to cetacean conservation [1].

Marine Protected Areas (MPAs) are distinct locations which are actively managed in order to protect and conserve their natural states [88]. Implemented through the designation of delineated boundaries, MPAs help regulate human activities and act as one of the key

management mechanisms available to policy makers to mitigate adverse anthropogenic impacts. These areas can be managed with specific restrictions, such as fishing quotas, access controls, seasonal limitations and no-take zones [8–12]. Monitoring, often associated with MPAs, can help provide a clear understanding of the species and biodiversity, within area boundaries, which can inform management tailored to benefit both sessile and mobile organisms, including migratory species [13–15]. MPAs can help protect cetaceans throughout key life stages such as breeding and calving, but may be less effective for mobile species, as the boundaries of MPAs are usually static and may not protect species across their entire range. A key challenge faced when delineating MPA boundaries and determining threat mitigation policies is data paucity. Due to the behavioural characteristics of cetaceans, these highly mobile species can be challenging to observe, resulting in data gaps during periods when species are not visible at the sea surface [16,17].

Limited available data at appropriate spatial and temporal resolutions can hinder the outcomes of many conservation efforts [18].

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Robust and large-scale surveys provide a snapshot of species occurrence [19]; however, infrequent or intermittent sampling can result in low temporal data representativity. Such knowledge gaps can limit our understanding of the causes and impacts of environmental pressures which, in turn, can restrict the effectiveness of management measures. These deficits can be addressed and mitigated using citizen science to collect high-resolution data, across a range of spatiotemporal scales, which might otherwise be infeasible to obtain through traditional research alone [20–23]. Additionally, citizen science can provide baseline datasets, from which ecosystem responses to future anthropomorphic changes can be compared, providing marine managers with a warning system for environmental change [18].

Marine mammal researchers within the field of environmental conservation are increasingly looking to develop citizen science projects as a means of increasing the amount of data collected which can be used to help identify areas of biological importance and temporal changes in species abundance [24]. Citizen science has the potential to benefit conservation science, policy-making and practice [25–28] by increasing survey effort and the amount of data collected, which in turn, can increase the likelihood of detecting environmental change [18]. In recent decades, the global use of citizen science has grown exponentially [29,30], and has highlighted a wide range of beneficial impacts for environmental conservation efforts, such as reduced financial constraints through volunteer schemes, improved public understanding of conservation issues and fine-grain data collection, which is imperative for monitoring, understanding and reducing anthropogenic impacts on biodiversity [28].

The Bay of Biscay offers a wide range of habitats for cetacean species, such as harbour porpoise (*Phocoena phocoena*), common bottlenose dolphin (*Tursiops truncatus*), striped dolphin (*Stenella coeruleoalba*), and Baleen whales (*Balaenopteridae*) [31,32]. Furthermore, bathymetry has been identified as a key factor influencing the species distribution, and habitat preferences of toothed whales within the Bay of Biscay, [33]. While these studies documented the spatial distributions of cetacean species within the study area, none have directly identified cetacean biodiversity hotspots.

Citizen scientists have been collecting data in the Bay of Biscay on cruise and ferry routes between Portsmouth and Santander since the mid-1990s. The use of these vessels as opportunistic research platforms has facilitated the collection of observational data over extended periods of time, with little or no cost [33,34]. Using trained volunteers to collect observational data on marine mammals from commercially active vessels, citizen science can further extend the longitudinal monitoring of marine mammals. Long-term data collected by citizen scientists can be used to highlight spatial trends, such as the distribution of biodiversity hot-spots, and help identify sites suitable for the implementation of MPAs and Important Marine Mammal Areas (IMMAs).

IMMAs are distinct locations identified as important for marine mammals, which may merit protection by being delineated as an area for conservation and/or monitoring [35]. The introduction of IMMAs has been advocated to better support the specific needs of highly mobile marine megafauna, including cetaceans [35]. As a non-statutory variant of MPAs, IMMAs can be employed globally to establish biodiversity networks which support marine mammal populations [36]. Through the implementation of IMMAs, it is possible to assess, monitor and delineate biodiverse areas of high conservation importance. Information on species distribution, biodiversity and ecological communities can be used to inform the marine spatial planning of human activities, in order to promote the sustainable use of natural resources and mitigate adverse anthropogenic impacts [36]. Additionally, the spatial analysis of biodiversity and integration of accurate, representative ecological data into MPA design can assist in achieving species spillover effects [15] which can in turn facilitate interconnectivity between adjoining MPA/IMMA sites [37–39]. This is of particular importance when establishing protection mechanisms for migratory and mobile species, which otherwise may not be protected from human activities

through static MPA networks.

This study utilized data from an ongoing citizen science project to investigate the spatial patterns of cetacean biodiversity in the Bay of Biscay and identify regions suitable for designation as MPAs or IMMAs.

2. Material and methods

2.1. Data collection

Citizen scientists, trained by ORCA (<http://www.orcaweb.org.uk>; [34]), collected data on cetaceans aboard the *Pont-Aven*, operated by Brittany Ferries. The Citizen scientists working on ORCA-led surveys came from a range of backgrounds and ages, including students, working professionals, and retired senior citizens. Reasons for participation varied on an individual-specific basis. Some aimed to develop skills which may help them find employment opportunities, whereas others were high-level employees who currently work on marine mammal policy and used the surveys as opportunities to see the animals they work to protect. However, the majority of those who took part in ORCA surveys were not employed in a scientific field, nor aspired to, but were members of the public who were interested in conservation and therefore, contributed to scientific work as citizen scientists [40].

Prior to survey, each ‘Marine Mammal Surveyor’ undertook a day-long course, in which they were taught taxonomic identification skills, survey protocol and appropriate behaviour on the bridge of ships. Those who undertook longer surveys across the Bay of Biscay, which were included in this study, usually had greater levels of experience and would have completed at least three ORCA surveys in preparation for data collection. The teams of four generally comprised three experienced surveyors, and one with less experience to help develop less experienced observers.

The vessel followed a relatively fixed transect route from Plymouth, UK, to Santander, Spain, returning to Portsmouth, UK, through the Bay of Biscay (Fig. 1) in the summer months (March–October) between 2006 and 2016. Surveys were undertaken during daylight hours, under favourable conditions (swell height ≤ 2 m, Beaufort Sea state ≤ 6). The vessel travelled at consistent speed with an average of 20.4 knots. Observations were conducted from the bridge (21.75 m deck height) using 7×50 Opticron binoculars. When a sighting occurred, the species identity, certainty of identification, and GPS location were recorded.

Survey teams consisted of four members, with two observers, one recorder, and one on rest. Individuals rotated roles every 30 min, and observers only undertook searching effort for 30 min at a time, to avoid observer fatigue. Standard distance sampling methodology was used (see Ref. [34] for details of distance sampling protocol). The starboard observer collected data from 90° starboard to 10° port, whilst the port observer searched from 90° port to 10° starboard. This allowed 20° overlap, should one observer miss species directly ahead. Simultaneously, the third active survey member recorded sightings and environmental conditions.

2.2. Data management and quality control

All data recorded by citizen scientists participating in ORCA surveys underwent checks by trained scientists to ensure a high level of quality control. Data retained by ORCA were stored in both physical and digital formats through the use of archives, log sheets and ESRI ArcGIS Geodatabases and relational databases. Both new and historic data were systematically checked using set protocols to ensure records are accurate, and that spatial data were formatted correctly. Additional checks were completed annually for any data collected within that year, to reduce the potential for erroneous data being archived.

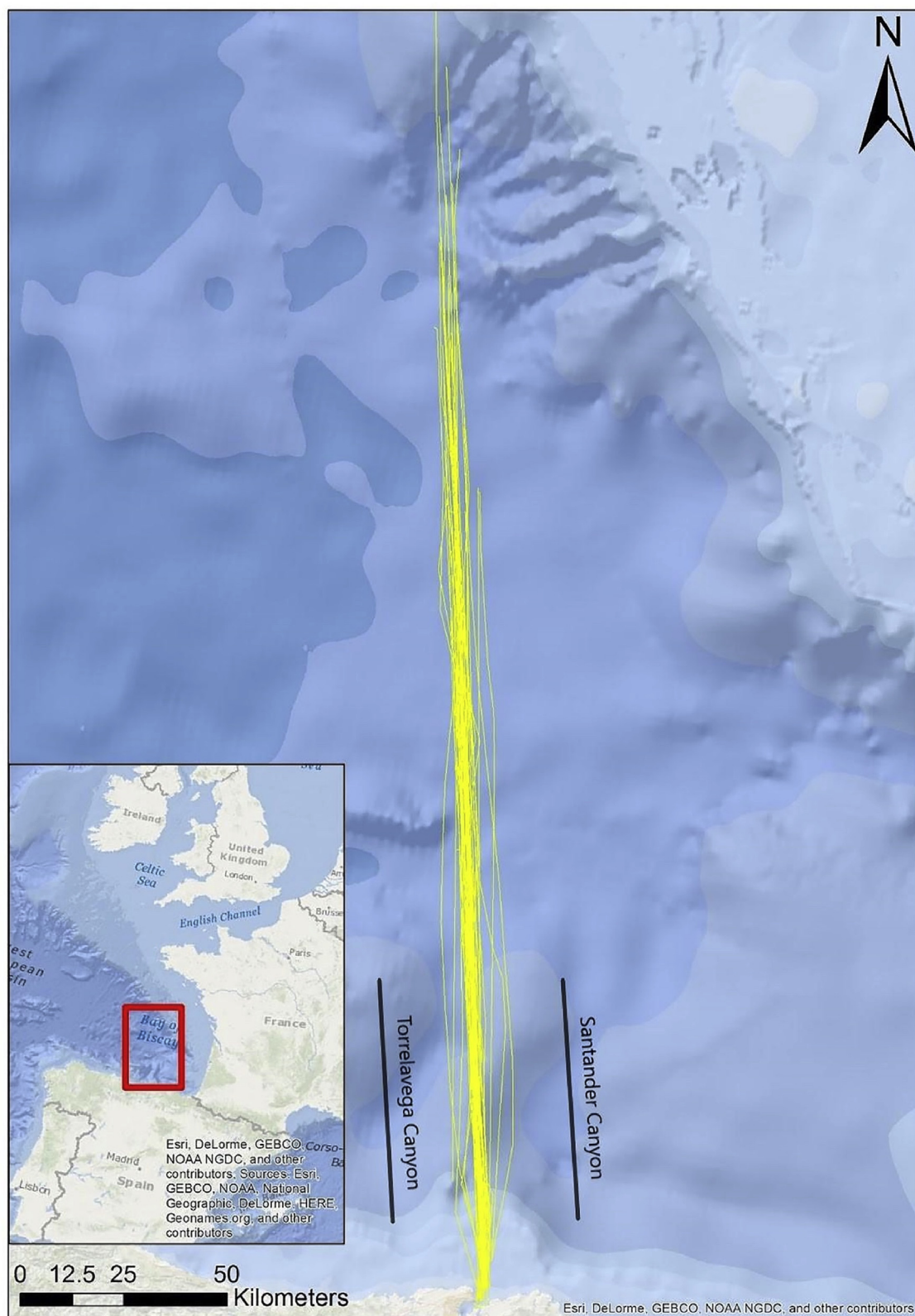


Fig. 1. Study area - The Bay of Biscay. Survey transects and vessel effort for the Pont-Aven throughout the 10-year study period.

2.3. Statistical analyses

Sixty-six crossings were carried out within the 10-year period. All sightings with uncertain species identification were omitted from statistical analyses. Data were analysed at a 10 km² grid resolution based

on spatial distribution within ArcMap 10.3 [41]. For each 10 km² grid, species richness, evenness, and biodiversity were calculated using Past 3.15 software [42]. Simpson's Diversity Index 1-D was calculated to explain the relationship between overall abundance of individual species classifications (richness), and to examine how evenly individual

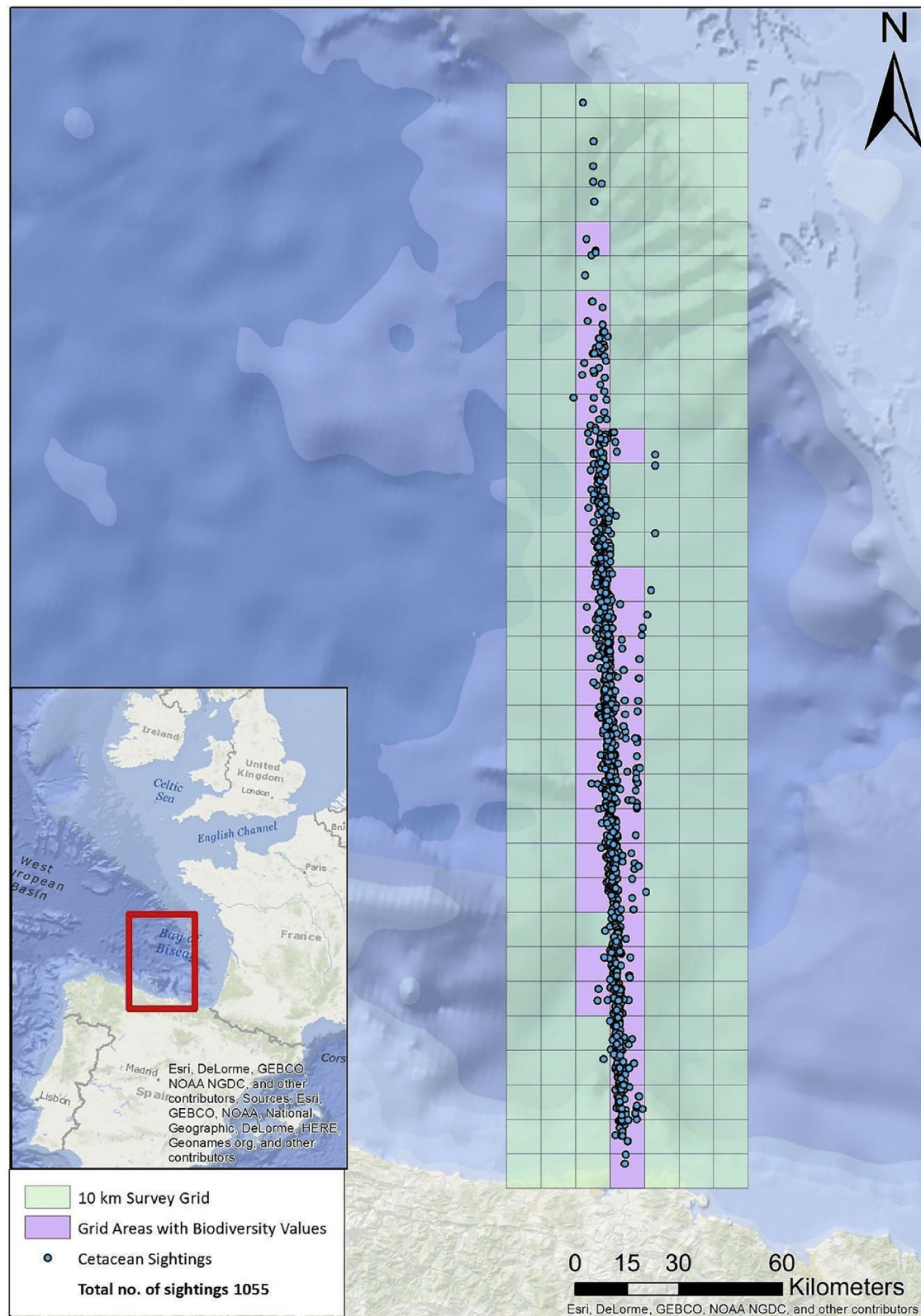


Fig. 2. Analysed sightings and 10 km² survey gridded areas with biodiversity values. Adapted from, Esri, DeLorme, GEBCO, & NOAA NGDC (2017).

taxa were spread (evenness) within each quadrat [43]. Richness was defined as the total number of species from a sample in a given location and evenness as a measurement of the relative abundance of species contributing to the richness of an area.

Simpson's Diversity Index (1-D) was calculated as follows:

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)} \right)$$

where n = Total no. individuals of a specific species; N = Total no. individuals of all species.

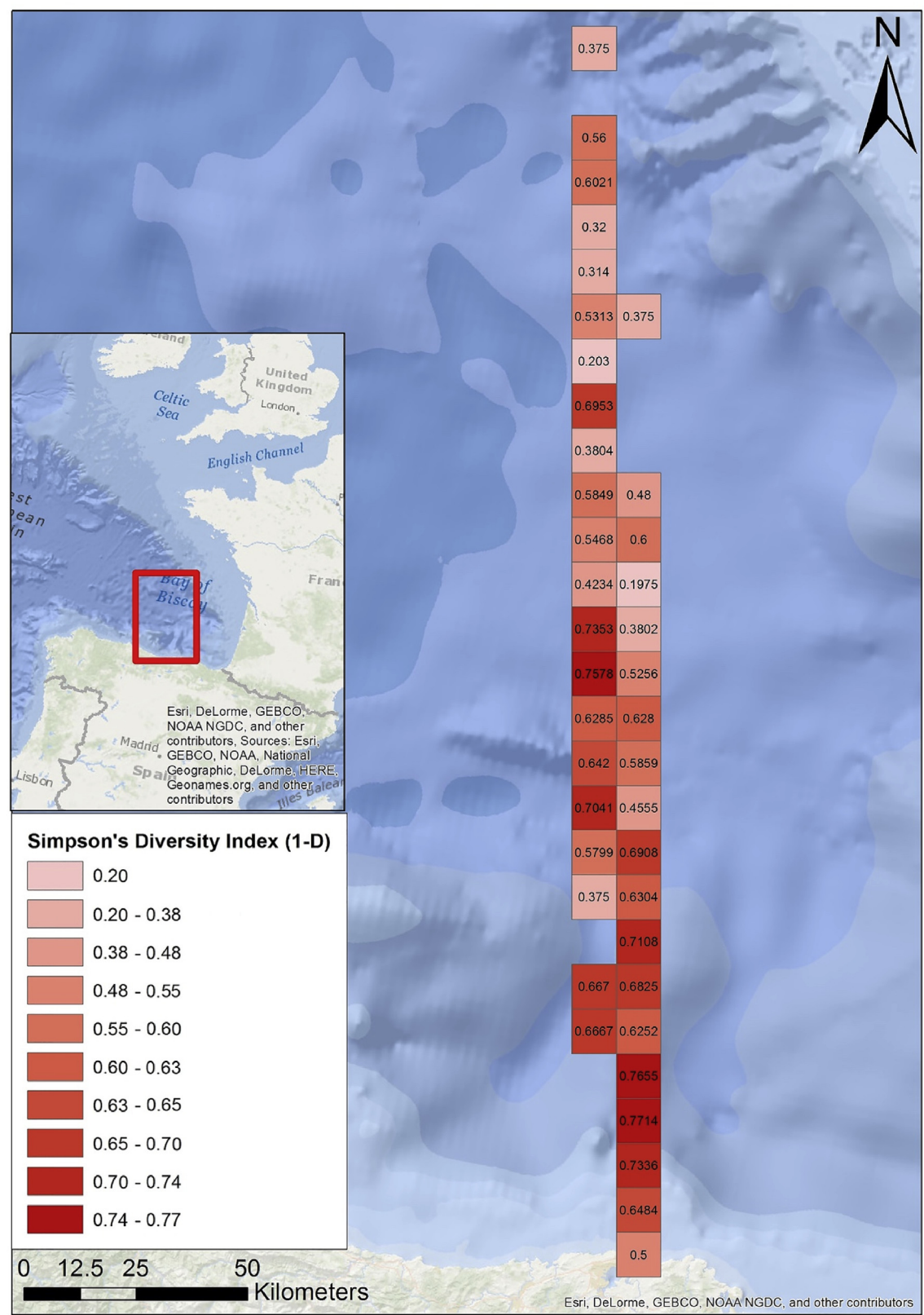


Fig. 3. Spatial distribution of biodiversity from the 10-year dataset. All values given as Simpson's Diversity Index (1-D).

Evenness (E) was calculated as follows:

$$E = \frac{D}{D_{max}}$$

where D = Diversity; Dmax = the total no. of species present

(maximum value of D).

3. Results

The statistical analyses included 1055 sightings and a total of 17

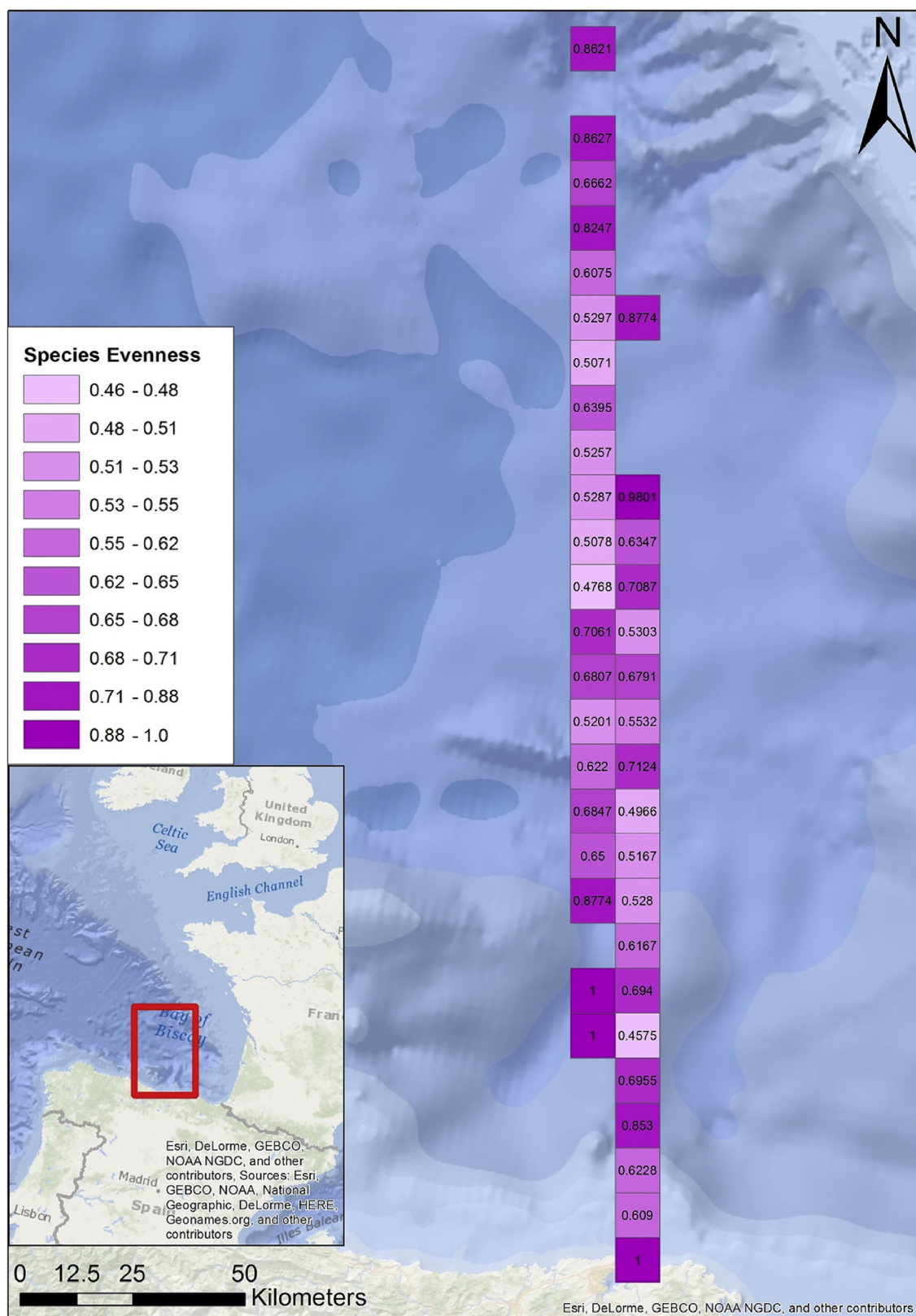


Fig. 4. Spatial distribution of species evenness from the 10-year dataset.

species were identified (Fig. 2; Appendix 1). Biodiversity indices were highest in the central and southern areas of the Bay of Biscay at around 44.9°N latitude. Biodiversity increased from the northern to the southern areas of the Bay of Biscay, with the highest value (0.77)

located near the continental shelf slope of the Iberian Coast (Fig. 3). Species richness was highest in the southern-most areas of the bay nearest to the Santander Canyon, and species richness decreased in northern areas of the study area (Fig. 5). Species evenness was found to

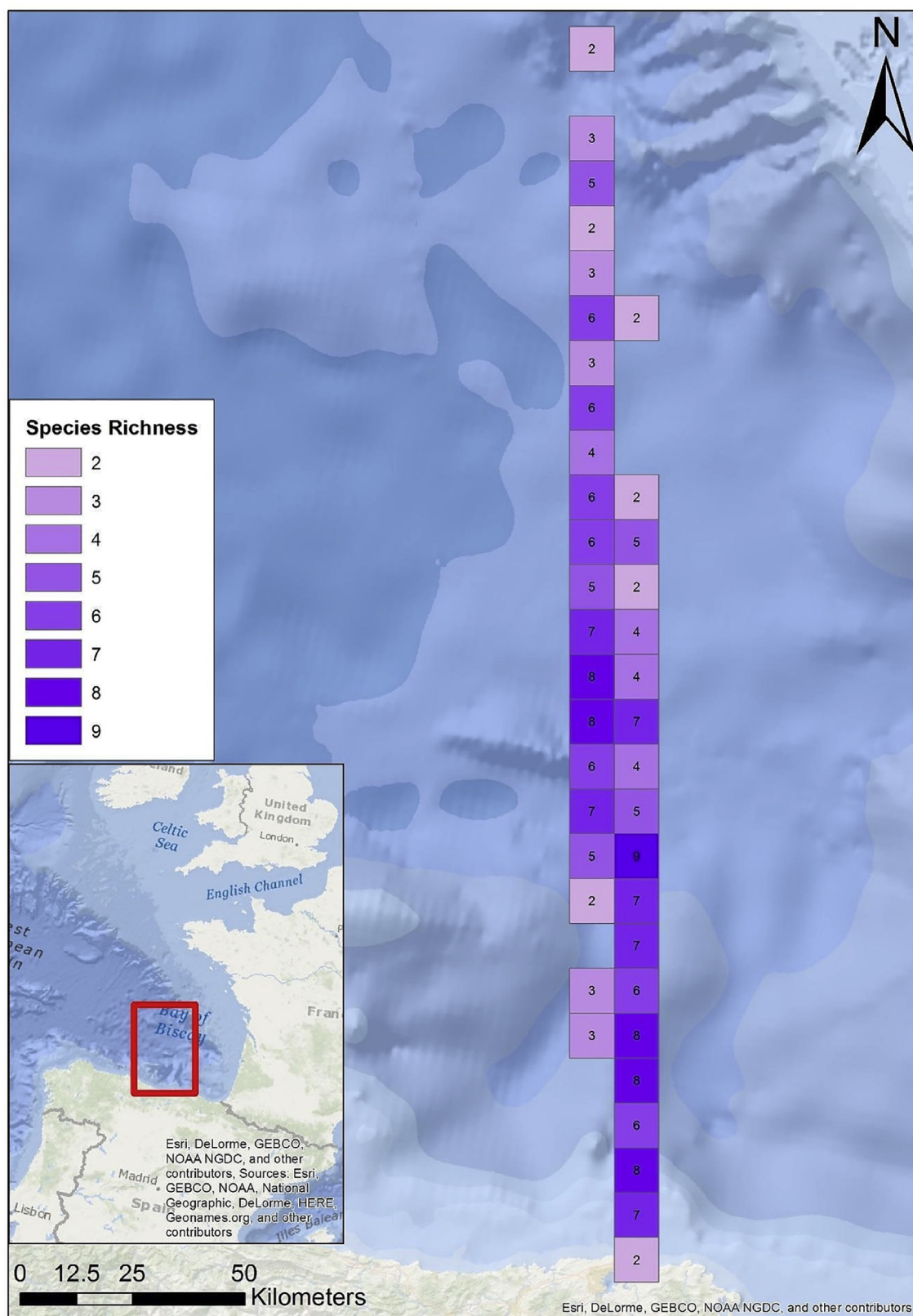


Fig. 5. Spatial distribution of species richness from the 10-year dataset.

be highest (0.8–1) in close proximity to canyon habitats and both the northern and southern continental shelf slopes of the Bay of Biscay (Fig. 4). Areas of high biodiversity were also identified in the central, deep-water regions of the Bay of Biscay (Fig. 3). Diversity did not

appear to be related to broad bathymetric conditions, with deep-water associated with both the highest (0.74–0.76) and the lowest (0.19) biodiversity indices (Fig. 3).

4. Discussion

Throughout the ten years of monitoring via citizen scientists, 17 species of cetaceans were recorded in the Bay of Biscay. Of these species, ten are listed as 'data deficient', two as 'near threatened', two as 'vulnerable', two as 'least concern', and one as 'endangered' on the IUCN Red List (Appendix 1; [7]). The area approximately 50 km north of Santander was the most diverse, with lower diversity towards the northern shelf edge. The areas of higher biodiversity fit the criteria outlined for IMMA implementation (Appendix B; [35,36]). The selection criteria comprise a range of key attributes designed to include as many potential biological, ecological and behavioural characteristics recognised to be important to marine mammals and prospective IMMAs need only satisfy one of the listed criteria and/or sub-criteria to be qualify for IMMA status [35]. The data from this study indicate that the Bay of Biscay meets these criteria as the habitats present are important to threatened and declining species; provide areas which consistently support populations throughout key life cycle stages, such as migration, feeding and calving; and has locations which support a high diversity of marine mammal species. The Bay of Biscay meets all categories of criteria (Criteria A, B, C, D).

The 10-year research period in this study indicates that despite potential fluctuations in environmental conditions which may affect the occurrence of cetaceans, the southern areas of the transect nearest to the Santander and Torrelevaga canyons were consistently more biodiverse than other areas. Diversity may have been highest in these areas as they provide a high variability of physiographic conditions that can support life [44], including nutrient upwelling leading to enhanced primary production, surface water convergence, transport of planktonic organisms, and the presence of thermoclines, baroclines and halocline gradients [45]. The geospatial distribution of biodiversity mirrored previous findings, with the highest recorded indices located near regions of steep, heterogeneous benthic habitats, such as near-coastal submarine canyons [46,47].

The near-coastal areas closest to the Santander and Torrelevaga canyons may be of high conservation value and could benefit from MPA designation through further scientific research, protection of ecosystem services, and management of human activity [48,49]. However, as non-statutory mechanisms for marine conservation, IMMAs alone may not fully protect marine mammals within the Bay of Biscay, and therefore, should be used in combination with statutory management mechanisms, or as tools to further identify areas of conservation quality which could benefit from monitoring and legal protection. Management mechanisms such as IMMAs should be designed to be easily integrated into existing policies and institutional structures. This is important for transboundary marine management of highly mobile species such as cetaceans to ensure that all habitats that cetaceans depend upon throughout their biological cycles are represented [50].

The central, deep-water pelagic areas of the Bay of Biscay indicated high biodiversity indices, although these locations were not expected to support high biodiversity, as they do not have the typical characteristics considered necessary to support an abundance of life, such as diverse habitat heterogeneity or topography which may facilitate upwelling [51–57]. Unlike the near coastal hot-spots, the spatial distribution of biodiversity in deep-water habitats may be less influenced by physiographic and hydrographic features [44]. Therefore, the high biodiversity observed over deep-water habitats may be due to species-specific physiological and behavioural characteristics such as surfacing intervals for respiration, hunting, communication and display [58].

Many of the species recorded in the Bay of Biscay, including short-beaked common (*Delphinus delphis*), striped, and Risso's dolphins (*Grampus griseus*), long-finned pilot (*Globicephala melas*), Cuvier's beaked (*Ziphius cavirostris*) and common minke whales (*Balaenoptera acutorostrata*) are listed as 'data deficient' under European assessments by the IUCN Red List (Table 1; [32]). The designation of an IMMA could prioritise further monitoring to inform policy makers about the current

status of the species and populations which use this area, and therefore facilitate appropriate conservation actions. Further monitoring in areas such as the Mediterranean Sea has aided the successful development of MPAs for cetaceans through improved understanding of natural environments [59]. Given the high biodiversity near the continental shelf slope of the Iberian Coast, these near coastal approaches meet IMMA selection criteria (Appendix B) and therefore, may benefit the most from IMMA protection. Further dedicated monitoring, or the analysis of existing datasets through the use of opportunistic citizen science could help address knowledge gaps and inform the protection of areas of importance, including those used by rare species.

4.1. Applications of citizen science in cetacean conservation

Citizen science has the capacity to complement dedicated professional surveys [18,34]. The combination of robust traditional surveys (e.g. Small Cetaceans in European Atlantic waters and the North Sea 'SCANS' and Cetacean Offshore Distribution and Abundance 'CODA') and long-term citizen science monitoring can highlight areas of importance such as those with high biodiversity to inform appropriate management [19,60]. Data collected through citizen science have been demonstrated to show similar trends to those collected by professional scientists [34]. Such similarities can be indicative of the potential value of citizen science, through validation of accuracy (dependent on methodology). However, citizen science is limited through other factors, including potential coverage and survey designs appropriate for platforms of opportunity and should therefore be seen as complementary to traditional surveys, rather than a replacement.

Cooperation between ferry companies and conservation organisations indicates that public-private-third sector collaboration is evolving positively [61]. The benefits of having ORCA-trained citizen scientists on board commercial and tourist vessels can extend into the transnational corporate world [62]. The integration of non-scientific organisations into academic research enables corporate social and environmental responsibility to be built into company policies. The willingness of commercial companies to welcome scientists onboard (e.g. Refs. [33,34,63,64]) is promising, and highlights that seafarers are interested in conserving the marine environment they work in. Brittany Ferries have been directly supporting dedicated research to reduce vessel collisions with large whales (Coxon, R., personal communication), with the Bay of Biscay highlighted as an area of concern. Furthermore, having volunteers on board non-research vessels has been shown to increase public awareness of marine environmental issues [65]. Members of the public who are aware of and sympathetic to environmental issues could become apathetic if their individual contributions, such as recycling, are perceived as futile within larger scale conservation efforts [66,67]. The use of citizen science can help engage individuals from non-technical backgrounds with academic research and civic activity, highlighting the importance of wider community engagement and participation [68]. Improved ecological understanding among the general public could enhance perceptions of the value of marine conservation efforts [69].

4.2. Barriers between citizen science and conservation

Citizen science has yet to be fully accepted by much of the scientific community given its innovative approach and relatively short history of widespread adoption, especially in the marine environment [70–72]. A survey of the scientific community found that citizen science was perceived to be less effective than traditional targeted research, potentially reducing its usage [70]. Key criticisms of citizen science research include weak study designs [73], inadequate participant training [29], poor standardisation of data and methodologies [74], and observational biases [75]. Poor survey methods can directly impact the accuracy and reliability of citizen science research, which in turn can erode confidence in the validity of findings on species abundance and density

which are considered essential parameters for assessing population demographics [76,77].

Accuracy is considered essential when assessing species population demographics [76,77], and citizen science surveys have shown similar results to traditional surveys within the Bay of Biscay (e.g. Refs. [34,47]. Replicability and comparability of results highlights the value of citizen science, which can provide a cost-effective means of data collection across a wide range of spatiotemporal scales [33,34]. Surveys on platforms of opportunity can help bridge knowledge gaps through the provision of data at finer scales of resolution, which otherwise may not be achieved with traditional science alone, due to constraints such as funding. Both traditional surveys and the use of citizen science have numerous benefits, which can be used to complement each other to help overcome constraints and shortcomings.

However, citizen science has associated limitations, as in this study, the survey extent was constrained to the limited range of ferries which are selected for safe navigation and economic considerations rather than for facilitating marine scientific research [33]. Therefore, the

spatial distribution of biodiversity cannot be extrapolated beyond the ferry routes. This survey design did provide an extensive temporal coverage of the survey area however, with ten years of data.

5. Conclusions

The results of this study show the long-term monitoring by citizen scientists can provide key information to identify areas of high biodiversity. Areas in the southern Bay of Biscay with varied bathymetry had the highest biodiversity and relatively rare cetacean species were also reported here, suggesting that these areas warrant further monitoring and likely protection. This area meets the criteria for IMMA designation, which would assist in the protection and conservation of the diverse cetacean species found in the Bay of Biscay.

Declaration of interest

None.

Appendix A. Species list

The species listed in Appendix A have been categorised using the International Union for Conservation of Nature (IUCN) Red List Classification to indicate the degree to which they are threatened. Species are assessed and classified into nine groups, Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD), Not Evaluated (NE) [78]. The scale of the assessments within Appendix A are given at a global (G) scale, or within Europe (E).

Table 1
Species list and associated population trends

Species Common Name	Binomial	IUCN Red List Classification (region of assessment)	Population Trend
Harbour porpoise	<i>Phocoena phocoena</i>	Vulnerable (E)	Decreasing
Bottlenose dolphin	<i>Tursiops truncatus</i>	DD (E)	Decreasing
Short-beaked common dolphin	<i>Delphinus delphis</i>	DD (E)	Unknown
Striped dolphin	<i>Stenella coeruleoalba</i>	DD (E)	Unknown
Risso's dolphin	<i>Grampus griseus</i>	DD (E)	Unknown
Long-finned pilot whale	<i>Globicephala melas</i>	DD (E)	Unknown
Killer whale	<i>Orcinus Orca</i>	DD (E)	Unknown
False killer whale	<i>Pseudorca crassidens</i>	Near Threatened (G)	Unknown
Northern bottlenose whale	<i>Hyperoodon ampullatus</i>	DD (E)	Unknown
Cuvier's beaked whale	<i>Ziphius cavirostris</i>	DD (E)	Unknown
Sowerby's beaked whale	<i>Mesoplodon bidens</i>	DD (E)	Unknown
True's beaked whale	<i>Mesoplodon mirus</i>	DD (E)	Unknown
Sperm whale	<i>Physeter macrocephalus</i>	Vulnerable (E)	Unknown
Common minke whale	<i>Balaenoptera cutorostrata</i>	Least Concern (E)	Unknown
Humpback whale	<i>Megaptera novaeangliae</i>	Least Concern (E)	Increasing
Sei whale	<i>Balaenoptera borealis</i>	Endangered (E)	Unknown
Fin whale	<i>Balaenoptera physalus</i>	Near Threatened (E)	Unknown

Appendix B. Important Marine Mammal Area Selection Criteria

Criterion A – Species or Population Vulnerability

Areas containing habitat important for the survival and recovery of threatened and declining species.

Criterion B – Distribution and Abundance

Sub-criterion B (i) – Small and Resident Populations

Areas supporting at least one resident population, containing an important proportion of that species or population, that are occupied consistently.

Sub-criterion B (ii) – Aggregations

Areas with underlying qualities that support important concentrations of a species or population.

Criterion C – Key Life Cycle Activities

Sub-criterion C (i) – Reproductive Areas

Areas that are important for a species or population to mate, give birth, and/or care for young until weaning.

Sub-criterion C (ii) – Feeding Areas

Areas and conditions that provide an important nutritional base on which a species or population depends.

Sub-criterion C (iii) – Migration Routes

Areas used for important migration or other movements, often connecting distinct life-cycle areas or the different parts of the year-round range of a non-migratory population.

Criterion D – Special Attributes**Sub-criterion D (i) – Distinctiveness**

Areas which sustain populations with important genetic, behavioural or ecologically distinctive characteristics.

Sub-criterion D (ii) – Diversity

Areas containing habitat that supports an important diversity of marine mammal species.

Appendix C. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.marpol.2019.103672>.

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