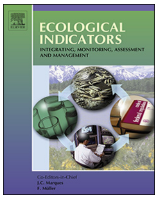
Ecological Indicators 93 (2018) 533–546

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



Original Articles

Marine biological value along the Portuguese continental shelf; insights into current conservation and management tools

Inês Gomes[a,b,*], Sergi Pérez-Jorge[c], Laura Peteiro[d], Joana Andrade[e], Juan Bueno-Pardo[a], Victor Quintino[a], Ana Maria Rodrigues[a], Manuela Azevedo[f], Ann Vanreusel[b], Henrique Queiroga[a], Klaas Deneudt[g]

[a] Departmento de Biologia & CESAM, Universidade de Aveiro, Campus Universitario de Santiago, 3810-193 Aveiro, Portugal
[b] Marine Biology Research Group, Ghent University, 9000 Ghent, Belgium
[c] MARE – Marine and Environmental Sciences Centre and Institute of Marine Research (IMAR) – University of Azores, 9901-862 Horta, Portugal
[d] Departamento de Ecoloxía e Bioloxía Animal, Facultade de Ciencias do Mar, Universidade de Vigo, 36310 Vigo, Spain
[e] Sociedade Portuguesa para o Estudo das Aves (SPEA), 1070-062 Lisboa, Portugal
[f] Instituto Português do Mar e da Atmosfera (IPMA), 1495-006 Lisboa, Portugal
[g] Flanders Marine Institute (VLIZ), InnovOcean Site, 8400 Ostend, Belgium

ARTICLE INFO

Keywords:
Assessment tool
Intrinsic value
Biodiversity
Ecological criteria
Conservation
Marine spatial planning

ABSTRACT

The valuation of nature is an inbuilt component of validating environmental management decisions and an important research field for different disciplines related to conservation, economy and ethics. Here, biodiversity was valued using an ecological approach based on the intrinsic value incorporated in biodiversity *per se,* regardless of any human association. The Marine Biological Valuation protocol was drawn upon the methodology of terrestrial valuation maps, to support the European MSFD environmental status assessment (descriptor 1 – biodiversity) and national marine spatial planning approaches. To apply the protocol on the Portuguese continental shelf we compiled and analyzed national biological databases for a wide taxonomic range of ecosystem components (seabirds, demersal fish, macrobenthos, marine mammals and sea turtles) and assessed the spatial overlap with existing and proposed conservation areas (Natura 2000 network). The resultant maps described patterns of biological value consistent with the physical and biological oceanographic conditions as well as local hydrodynamics of the Portuguese continental shelf. The results of our approach confirm previously identified valuable areas for protection (particularly in the northern and central regions), but also highlights the value of currently unprotected sites, mainly in the southern region. Biological valuation maps showed to be comprehensive tool to compile and spatially analyze biological datasets. By drawing attention to subzones of biological importance, it constitutes a valuable instrument in making appropriate-scale decisions on the spatial allocation of human activities in the context of the Portuguese marine spatial planning, currently facing the pressure and impacts of increased maritime exploitation.

1. Introduction

Biological diversity is recognised as the foundation of healthy ecosystems (Hector and Bagchi, 2007; Worm et al., 2006) and its conservation an important aim of environmental management (Brooks et al., 2006). The valuation (or "attributing importance/weight") of nature is an inbuilt component of validating environmental management decisions. Although the quantification of the wide-ranging value of biodiversity is currently a significant subject of investigation for conservation, economy and ethics disciplines, the methodologies have yet to reach a consensus amongst researchers. In fact, much debate still surrounds the concepts of biological diversity and biodiversity itself. The key challenge is to find ways to evaluate the multidimensional diversity concepts (including all biotic variation from genes to ecosystems level) in useful and operational ways (Purvis and Hector, 2000).

In its broad sense, biodiversity is valued regarding the views of anthropocentrism, as having a transaction and/or utility value (a socio-economic relation to humans) or holding an intrinsic biological value. Valuing nature requires therefore a complex combination of economic, socio-cultural and ecological perspectives (Laurila-Pant et al., 2015; Scholte et al., 2015). An ongoing debate exists around the methods valuing nature to reflect a realistic and integrative contribution of

---

* Corresponding author at: Departmento de Biologia & CESAM, Universidade de Aveiro, Campus Universitario de Santiago, 3810-193 Aveiro, Portugal.
E-mail address: istgomes@gmail.com (I. Gomes).

https://doi.org/10.1016/j.ecolind.2018.05.040
Received 17 November 2017; Received in revised form 23 April 2018; Accepted 16 May 2018

biodiversity in decision making (Chan et al., 2016).

Valuing biodiversity and ecosystem services in monetary terms (assigning a metric value to ecosystem components benefiting humankind) (Costanza et al., 1997) is a contemporary trend (Kubiszewski et al., 2017) enshrined into a number of international frameworks, such as the European Union 2020 Biodiversity Strategy, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), the Millennium Ecosystem Assessment (MA) and in marine policies like the European Marine Strategy Framework Directive (MSFD). Even though there are several classification systems to economically value biodiversity (see de Groot et al., 2002), a unified framework to measure marine monetary metrics in environmental management is still missing (Nahlik et al., 2012). Monetary evidences are believed to be easily conveyed to a broad audience and assimilated into conservation policymaking (Bräuer, 2003). Also, economic valuation can be a pragmatic way forward to add to scientific and ethic approaches to reach conservation goals; a strategy used in other domains like public health and education (Scharks and Masuda, 2016). Several studies have already calculated coastal and marine ecosystem services in different settings: estuarine waters (Barbier et al., 2011), coral reefs (Pendleton, 1995), artificial reefs (Polak and Shashar, 2013), mangrove forests (Huxham et al., 2015), sea grass meadows (Tuya et al., 2014), open sea (Ressurreição et al., 2011) and the deep sea (Jobstvogt et al., 2014). However, most critics to environmental economic valuation point out the fact that many financial proxies cannot reflect the highly complex and dynamic role of biodiversity to human wellbeing (Bartkowski et al., 2015). This is especially true in the marine setting, with fundamental physical and biological differences when compared to the terrestrial environment (Carr et al., 2003). For instance, the relative "openness" of marine populations (i.e., higher rates of import and export than their terrestrial counterparts) along with the way anthropogenic pressures are more diffuse in the marine environment, require broader spatial and temporal scale approaches to value biodiversity in ecologically meaningful ways. Also, several arguments have emerged among conservationists that conventional economic approaches are inadequate for conservation issues since they quantify ecosystem services as marketable, and consequently, replaceable commodities (Gómez-Baggethun et al., 2010; Peterson et al., 2010) contradicting conservation targets (Callicott, 2006; Fanny et al., 2015). Spash (2015) argued that this economic logic of natural systems and its offset principle, does not seek to prevent or reduce biodiversity devastation, but to legitimize it.

A complementary approach values biodiversity through its sociocultural value; investigating non-monetary human perceptions regarding ecosystem services (Daniel et al., 2012; Kenter et al., 2015). These valuation techniques are however constrained to landscapes greatly shaped by human direct influence (Martin-López et al., 2012) and less competent in offshore marine areas (but see Christie et al., 2017). In the marine environment, the quantification of this sociocultural component has been mainly treated within the context of marine protected areas (Angulo-Valdés and Hatcher, 2010; Petrosillo et al., 2007).

Finally, the ecological approach to value of biodiversity is based on the intrinsic value of biodiversity *per se,* regardless of any human association. This notion has been the basis not only for environmental ethics but also for biological conservation disciplines. Whether it is based on a philosophical view, or supported by available scientific methods, intrinsic values in nature are now widely accepted by conservationists (Cafaro and Primack, 2014; Doak et al., 2014; Vucetich et al., 2015). In order to reduce the subjectivity of "inherent values", various systematic decision supporting tools have been developed, using biodiversity metrics and spatial analysis to meet conservation targets (e.g. Airamé et al., 2003; Villa et al., 2002). Some studies identify areas of ecological importance, focusing on individual taxa (Fishpool et al., 1998), groups of species (Eken et al., 2004), habitats (Ward et al., 1999), using multiple ecological criteria (Roberts et al., 2003) or highlighting hotspots of rare/endemic species or high species richness (Myers et al., 2000). At a global scale, the Convention on Biological Diversity (CBD) has adopted a scheme to recognize 'Ecologically or Biologically Significant Marine Areas' (EBSAs) in need of protection. Seven scientific criteria are used to define EBSAs (Dunn et al., 2014): uniqueness or rarity; special importance for life-history stages; importance for threatened, endangered or declining species and/or habitats; vulnerability, fragility, sensitivity, or slow recovery; biological productivity; biological diversity; and naturalness.

The Marine Biological Valuation protocol presented here (Derous et al., 2007a, Derous et al., 2007b) was drawn upon the methodology of the terrestrial valuation maps, to fulfill the emergent need on solid spatial information to support marine spatial planning approaches. The protocol developed by Derous et al. (2007c) uses valuation criteria based on a thorough review of academic literature and international legislative documents on marine biological assessment by a panel of experts from Project BWZee – A Biological Valuation Map for the Belgian Continental Shelf. Unlike the EBSA protocol, aiming at identifying areas in need of protection, including criteria related to human impacts, the method reflects on "the inherent value of marine biodiversity, without reference to anthropogenic use". Initially developed for the Belgian part of the North Sea, it has also been applied to the shallow Belgian coastal zone (Vanden Eede et al., 2014) , Azores (Rego, 2007), Denmark (Forero, 2007) and Spain (Pascual et al., 2011). Also, Weslawsli et al. (2009) used a modified version to assess the biological value of the benthic communities in the southern Baltic Sea.

Here, we applied the protocol in the continental Portuguese shelf, using available biological datasets for the distribution and abundance of marine organisms. These maps can serve as integrative baseline information within the European MSFD environmental status assessment (descriptor 1 – biodiversity) and to define priority conservation areas in marine spatial planning (MSP).

Given the contemporary pressure and competitiveness on marine resource exploitation in the maritime setting, meaningful initiatives integrating full spatial coverage biological datasets are crucial for the monitoring of biodiversity (Golden et al., 2017). This is particularly true in the Portuguese case, with one of the largest continental shelf areas in the European Union and where the National Ocean Strategy 2013–2020 is set on the "blue growth" development model. The Portuguese MSP plan establishes the legal basis for the national policy on marine spatial planning and management, using the "Plano de Ordenamento do Espaço Maritimo POEM 2008–2012" (INAG, 2012) as the national reference situation for coastal and ocean planning. However, concerns have arisen that the framework is mainly driven by economical concerns, with environmental conservation coming second to economic goals (Frazão Santos et al., 2015, 2014). Calado et al. (2010) stated that the major operational challenge encountered in developing the Portuguese MSP was the access to suitable quality data and the lack of implementation tools to facilitate an effective public discussion. In this sense, the specific objectives of this work are: (i) to explore, compile and summarize national marine biological databases; (ii) to apply the marine biological valuation approach on the Portuguese continental shelf waters (iii) to assess the spatial overlap of the valuation scores with marine conservation areas (Natura 2000 network) and (iv) to examine the significance of our results in the context of the Portuguese marine spatial planning. To our knowledge this is the first published attempt to combine and spatially evaluate data for a wide taxonomic range of ecosystem components (seabirds, demersal fish, macrobenthos, marine mammals and sea turtles) at the scale of tens of kilometers along the continental Portuguese shelf.

2. Material and methods

2.1. Study area

The Portuguese continental shelf extends from the Galicia Bank to the Gulf of Cadiz for approximately 900 km in length, averaging a width

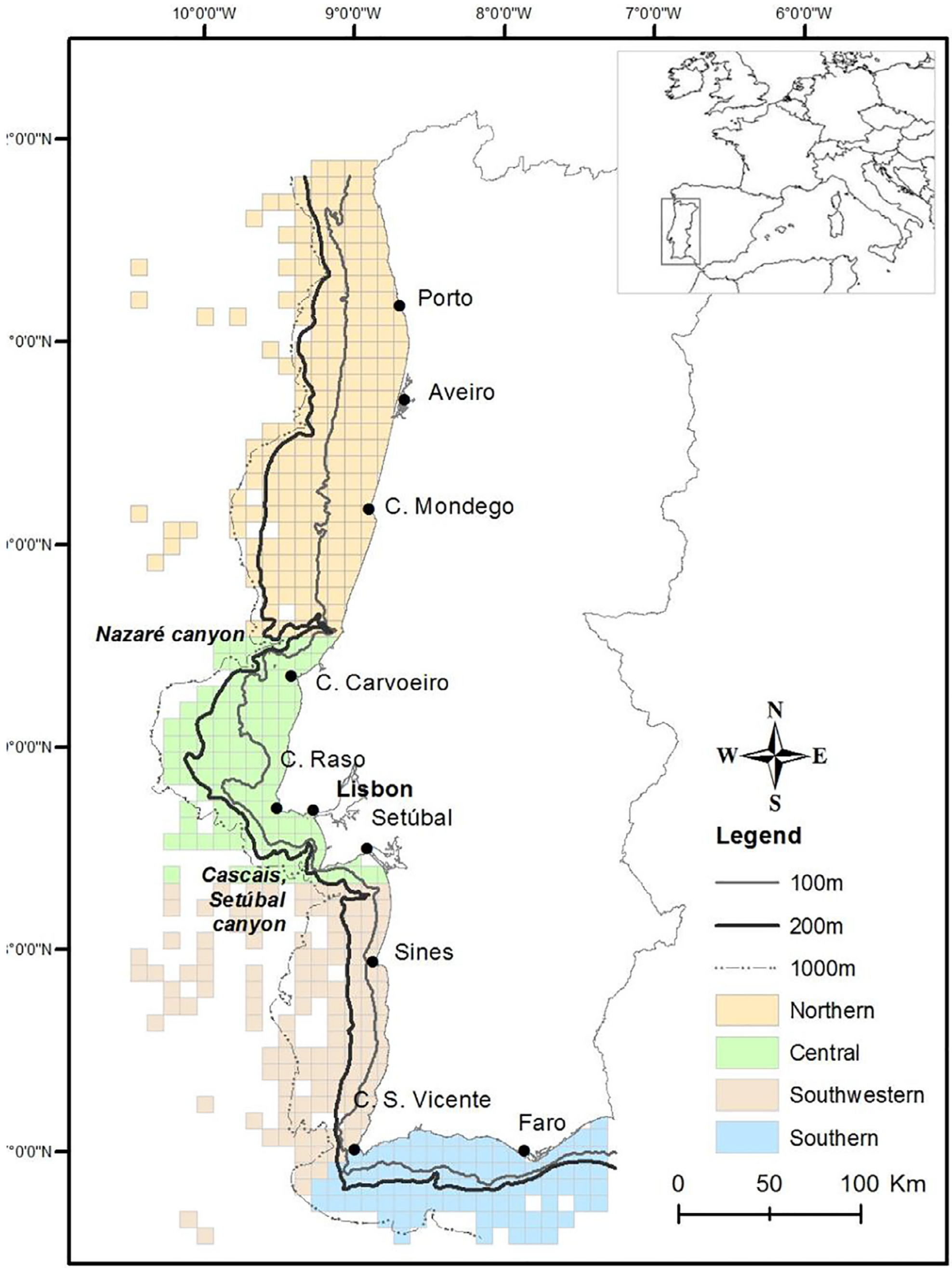


Fig. 1. Overview of the study area illustrating the subzones used for biological valuation (grid cells 9 km × 9 km) around the Portuguese continental shelf waters. The colour scheme represents the region limits used to assist in interpreting the results. Bathymetric lines show the 100 m (dark grey), 200 m (black) and 1000 m (dashed line) depth contours. Some important topographic features and locations cited in the text are also shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of approximately 45 km, and bordered by an irregular and steep shelf-break at around 160 m (Fig. 1). The shelf is characterized by a variety of sediment types (Martins et al., 2012) and cleaved by three main deep submarine canyons Nazaré, Cascais/Lisbon and Setúbal, representing geo-morphological and hydrological margins (Oliveira et al., 2007). In the western margin, the shelf northern sector is moderately wide (up to 60 km), and receives significant input from rivers, being a high-energy environment exposed to NW swells and high biological productivity. Distinctively, the southern sector (about 10–20 km wide), receives less riverborne input, has a steeper slope and is subjected to a low energy regime with swells predominantly from SW-S and SE (Mil-homens et al., 2007). In the southern margin the continental shelf is generally narrow and further characterized by relatively shallow depths (110–150 m) of the shelf break. Being situated at the northern limit of the Eastern North Atlantic Upwelling Region, the Portuguese continental coast is strongly influenced by seasonal upwelling events (Relvas et al., 2007); from approximately June to October bringing cold and nutrient-rich waters to the surface, while warmer offshore waters reach the shelf from November to May.

Our study area covered 41866.5 km^2, representing 13% of the Portuguese economic exclusive zone (EEZ, 327 667 km^2). Since it covers a large area with great topographic and oceanographic variability, it was subdivided into 4 main regions (northern, central, southwestern and southern) to assist in interpreting the results. For further analysis, each region was divided into grid cells of 9 km × 9 km (see Fig. 1). These grid cells were defined as subzones within the study area

Table 1

Sampling period, method, number of records, number of species and selected and ecologically significant and habitat forming species per ecosystem component; Number and percentage (%) of subzones with data, out of the total number of subzones; Spearman correlation between the biological valuation scores per ecosystem component and the total biological valuation score.

Ecosystem component	Sampling period (Reference)	Sampling method	Number of records	Number of species	Ecologically significant species	Habitat forming species	Number of subzones with data (% of total)	Spear. corr.
Macrobentos	2007 (Martins et al. 2013)	145 stations (0.1 m^2 Smith–McIntyre grab, sieved on board over 1 mm mesh size)	6526	603	*Protodorvillea kefersteini, Pisione remota, Asbjornsenia pygmaea, Magelona johnstoni, Urothoe pulchella, Fabulina fabula, Abra alba, Galathowenia oculata, Lumbrinerides amoureuxi, Euchone rubrocincta, Lysidice unicornis, Sternaspis scutata, Heteromastus filiformis, Psammogammarus caecus*	*Lanice conchilega, Sabellaria spinulosa*	115 (21%)	0.46
Birds	2004–2012 SPEA	15,818 observations (European Seabirds at Sea-ESAS-protocols	15,819	67	*Puffinus mauretanicus* *Calonectris diomedea* *Morus bassanus, Larus michahellis*		534 (97%)	0.80
Demersal Fish	2008 IPMA (Chaves, 2008)	88 stations (Bottom trawl surveys, average of 3.5 knots, each haul lasting 30 min. Mesh size of 20 mm.	1494	156	*Abralia (Asteroteuthis) veranyi, Alloteuthis, Illex coindetii, Loligo vulgaris, Sepiolidae, Todaropsis eblanae, Engraulis encrasicolus, Sardina pilchardus*		86 (16%)	0.25
Marine Mammals and Sea Turtles	2004–2012 SPEA	581 opportunistic observation	582	16	*Balaenoptera acutorostrata* *Phocoena phocoena, Caretta caretta*		241 (44%)	0.38

which could be scored relative to each other, against a set of biological valuation criteria. The size of the subzones (grid cells size) was chosen taking into consideration the total size of the study area, the sampling effort of the available data and on the basis of ecologically-meaningful parameters, like the mobility and dynamics of the biodiversity component under consideration. Even though smaller grid cells would make more sense in the case of relatively immobile benthic organisms when compared to highly mobile birds or marine mammals, the considerably lower sampling effort subjacent to some datasets led us to the decision of using an equally sized grid cell for all components.

2.2. Databases

This study included five major marine ecosystem components (macrobenthos, birds, demersal fish, marine mammals and sea turtles) for which sufficient and adequate spatial distribution data were available for the Portuguese continental shelf (Table 1). Given the satisfactory data coverage in the entire study zone, no use was made of full coverage spatial distribution predictive models, avoiding interpolation methods whose accuracy could not be assessed.

We run the analysis on four major components: macrobenthos, birds, demersal fish and marine mammals. The demersal fish component included pelagic species, cephalopods and crustaceans. Sea turtles were not assessed as a separate component, but included in the marine mammals component because of the small size of the reptiles 'dataset and the fact that the underlying observations originated from the same monitoring surveys. Prior to the analysis, general data quality control was applied on all databases and taxonomy was confirmed using the World Register of Marine Species Taxon match (WoRMS Editorial Board, 2017).

For the macrobenthos component, the database covered one sampling year and included a total of 145 sites, distributed in perpendicular lines to the coastline, between 13 and 195 m water depth (Martins et al., 2014, 2013). One sediment sample was collected at each site with a 0.1 m^2 Smith–McIntyre grab for macrofauna extraction (sieved on board over 1 mm mesh size) and identified to species level whenever possible, with a total of 26,315 animals sampled and 603 species identified.

For the demersal fish component data was used from the 2008 demersal autumn research trawl survey carried out by IPMA (Instituto Português do Mar e Atmosfera) as part of the National Programme for Biological Sampling (PNAB/EC Data Collection Framework). Survey sampling stations were spread along the continental shelf waters, covering depths between 20 and 500 meters. The bottom trawl (14 m headline; ground rope with rollers; 20 mm cod-end mesh size) fishing operations were carried out during daylight at an average speed of 3.5 knots, each haul lasting 30 min (Chaves, 2008). We used the central point of the line survey as a fishing station and the number of individuals per hour of trawl as the abundance index. There were a total of 88 fishing stations at 3 different depth levels: 20–100 m, 101–200 m and > 200 m, identifying 99 species of fish, 13 of cephalopods, 24 species of crustaceans and 43 species of other groups (echinoderms, cnidarians, bivalves, gastropods, polychaetes, ascidians and nudibranchs).

The birds, marine mammals and sea turtles database was made available by the Portuguese Society for the Study of Birds (SPEA). Sea bird, marine mammal and reptiles census (2004–2012) followed standard European Seabirds at Sea (ESAS) protocols for data collection (Camphuysen and Garthe, 2004). It consists of observation units of 5 min each, during a continuous route (linear transects), allowing the calculation of animal density estimates for the prospected area (number of animals/km^2). All animals in contact with water within 300 m of the survey transect were counted, and birds in flight were assessed using the snapshot method. More than 19,000 km^2 were surveyed, resulting in more than 200,000 bird observations (belonging to 61 species), 542 marine mammals' sightings (11 species recorded) and 39 observations of sea turtles (1 species recorded). Based on vessel speed and transect width, the surveyed area was calculated and density was estimated as the total number of observed animals divided by the area covered. However, concerning the marine mammal database, some methodological constraints associated with untrained observers might have resulted in species misclassification and in the high proportion of 'non-identified' cetacean records. Also, during ESA dedicated surveys, only one quadrant within 300 m of the survey transect was covered, missing the presence of cetaceans a larger distance from the boat.

2.3. Marine biological valuation protocol

The protocol employed in this study was thoroughly described by Derous et al. (2007c). Within the study area, a set of assessment questions were selected based on the criteria of rarity, aggregation and fitness consequences and applied to the different subzones. Assessment questions chosen were:

- Q1: Is the subzone characterized by high counts of many species?
- Q2: Is the abundance of certain species very high in the subzone?
- Q3: Is the presence of rare species very high in the subzone?
- Q4: Is the abundance of rare species very high in the subzone?
- Q5: Is the abundance of ecologically significant species (ESS) high in the subzone?
- Q6: Is the species richness (SR) high in the subzone?
- Q7: Is the abundance of habitat-forming species (HFS) high in the subzone?

Similarly to Vanden Eede et al. (2014) in a study of the Belgian coast, the analysis was based on the R-script developed by the Flanders Marine Institute (VLIZ) (Deneudt, 2013) adapted to the available biological data. Assessment questions were transformed into mathematical algorithms (see Supplementary information Table S.1 for full description) and applied to each ecosystem component dataset separately. This resulted in a numerical output further scored into a semi-quantitative classification of five classes. In each subzone, the total scores for all assessment questions were added per ecosystem component (each assessment question having an equal weight) resulting in a biological value (BV) score per subzone. The ecologically significant species and habitat forming species were selected based on expert knowledge and/or based on the DEVOTES Keystone Catalogue (Smith et al., 2014) and are listed in Table 1. The total BV was calculated for each subzone by averaging the values of the various ecosystem components (when there was only one ecosystem component, the total value assumed its score) and classified into a five value scoring system: 1 = Very Low, 2 = Low, 3 = Medium, 4 = High, 5 = Very High. These scores were displayed on colour graduated BV maps. The correlation between each component's BV and the total BV scores was measured by calculating the Spearman correlation.

Data availability values were determined by the number of samples (/observations) of each component taken (/made) in each subzone. It was calculated for each ecosystem component and for all components together, and divided into a three value scoring system: 1 = Low, 2 = Medium, 3 = High. The reliability indices scored how many assessment questions were answered per subzone, compared to the total number of possible questions. A reliability valuation map (scoring 1 = Low, 2 = Medium, 3 = High) was created for each component and for all components together. It displays the "trustworthiness" of the data; the value of subzones with less available data for all ecosystem components are scored as being less reliable than subzones valued on all the ecosystem components and should be consulted and discussed together with the BV map for a better interpretation of the overall results.

2.4. Hotspot identification

The Hotspot spatial statistics analysis (ArcMAP 10.1) spatially clustered subzones with either significant high or low values. This tool identifies hotspots by examining each subzone within the context of neighboring elements (Getis and Ord, 1992), evaluating the spatial association of a variable within a specified fixed distance band of a single point (in this case, the geometric centroid of each grid cell). In this sense, isolated large value cells were considered as outliers. We set up the distance threshold so as to include three neighbors of a grid cell. The result is a map of standardized z-scores reflecting the average BV within the defined radius relative to the whole domain, which can be compared to expected values under a normal distribution. Setting a confidence level of 95% delimits areas of spatial significance at z-values $+1.96$ standard deviations from the mean for hotspots, and -1.96 standard deviations from the mean for coldspots.

2.5. Spatial overlap

2.5.1. Conservation areas

We investigated the spatial overlap of the total biological value obtained in this study with Natura 2000 (N2000s) marine conservation areas. Geographic Information System layers for N2000s were obtained from the Portuguese ICNF (Institute for Conservation of Nature and Forest). This European network of nature protection is composed of sites designated under the Birds Directive (Special Protection Areas, SPAs) and the Habitats Directive (Sites of Community Importance, SCIs and Special Areas of Conservation, SACs). Here, we compared our results with the recently expanded marine SPAs and with the formalized proposal for the creation and expansion of marine SCIs, which await the approval by competent national authorities. Some already designated SCIs include littoral land sites covering a narrow strip of marine area of up to 20 m deep, and were not considered here. For full illustration of N2000 SPAs and SCIs in continental Portugal see Supplementary information Fig. S.1.

In Portugal, 7 SPAs incorporate marine areas comprising 26% of the continental shelf area (6188 km^2): Ria de Aveiro, Aveiro/Nazaré, Ilhas Berlengas, Cabo Raso, Cabo Espichel, Costa Sudoeste and Ria Formosa. These areas have been created based on the available information of occurrence, distribution and reproduction of numerous seabird species. The spatial overlap analysis was performed using the ArcGIS® software by Esri. The polygons corresponding to N2000 SPAs were used to quantify the area (in km^2) overlapping the different subzone BV scores. Finally we overlapped the total BV Hotspots with the current marine SPAs and proposed SCIs included in the technical proposal recently submitted by the national nature and biodiversity conservation authority.

2.5.2. Habitat maps

Lastly, we used the EUSeaMap (Populus et al., 2017) broad-scale seabed habitat maps (available at www.emodnet-seabedhabitats.eu) to analyze the association between the total valuation outputs with local physical characteristics. Habitats were classified according to EUNIS (European Nature Information System) classification system which provides a common and comparable European reference set of habitat types: "rock", "coarse sediment", "mixed sediment", "sand", "muddy sand", "sandy mud" and "mud". In addition, we used the biological zonation for habitat characterization based on a vertical scheme reflecting changing conditions of light penetration/attenuation and disturbance of the seabed by wave action: the infralittoral, the circalittoral, the deep circalittoral and the upper slope. The infralittoral zone extends from the intertidal seafloor to a boundary marking the end of favorable light conditions for the growth of seagrass and green algae. The circalittoral zone extends to a maximum depth at which the seabed is influenced by waves (where depth is ≤½ wavelength) and the deep infralittoral and upper slope expand to a maximum depth of 200 m and

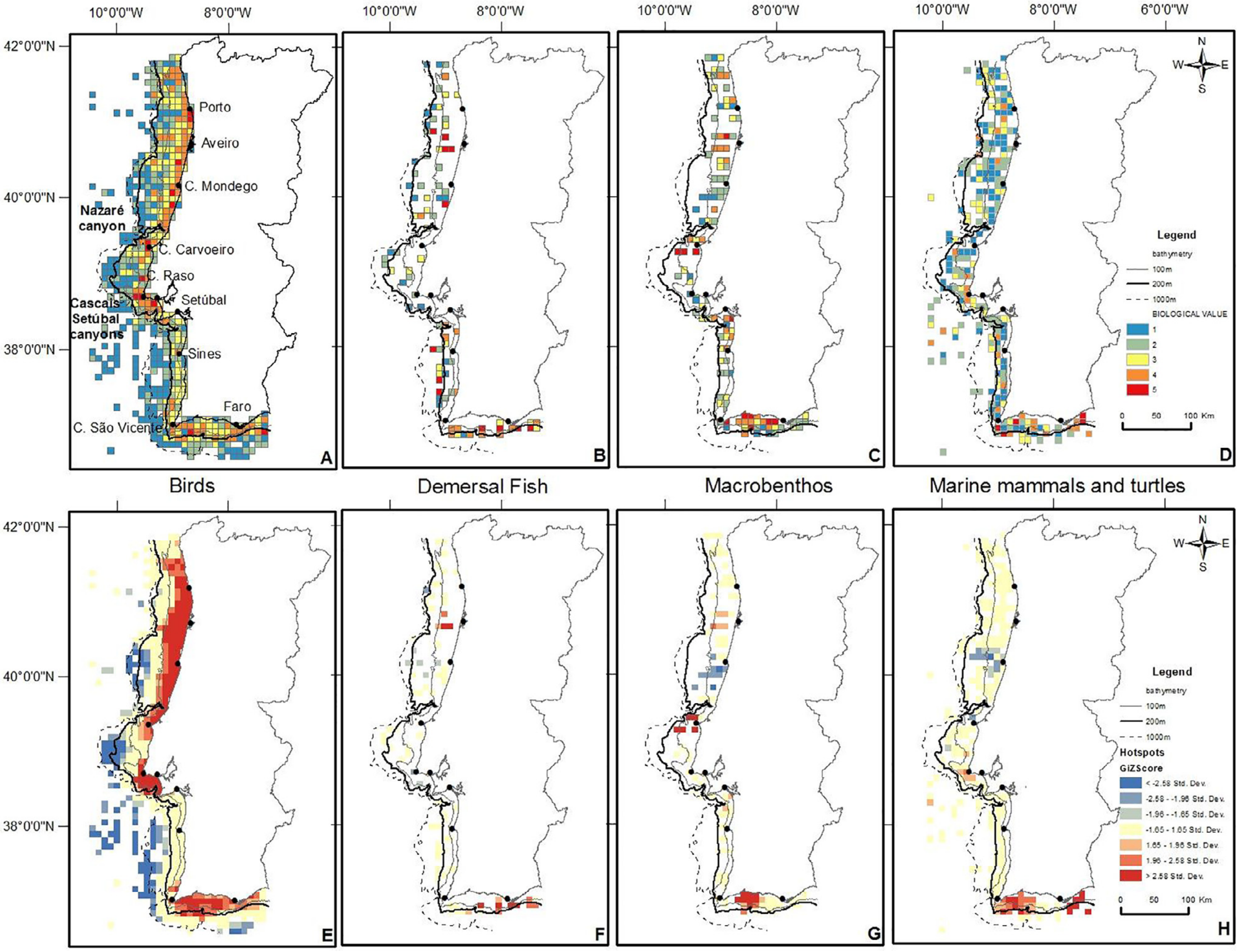


Fig. 2. Biological valuation maps for each ecosystem component: **A** birds, **B** demersal fish, **C** macrobenthos, **D** marine mammals and turtles (with common legend) scored into a five value scoring system: 1 = Very Low, 2 = Low, 3 = Medium, 4 = High, 5 = Very High. Hotspot classification for each ecosystem component: **E** birds, **F** demersal fish, **G** macrobenthos, **H** marine mammals and turtles (with common legend) showing z-scores using 95% confidence levels to determine the areas of spatial significance.

750 m respectively. Independent one-way ANOVAs, followed by post-hoc Tukey tests, were performed to test any effect of each factor (substract type and biological zone) on total BV.

3. Results

3.1. Biological value (BV) and hotspots classification

The BV maps for each assessment question, data availability and reliability indices per ecosystem components can be seen in Supplementary information Figs. S.2–S.5. When looking at total data distribution (all components together), there were 546 subzones with data (covering an area of 41866.5 km^2). The bird component contributed with the highest amount of data for the total valuation, followed by the marine mammals and turtles, macrobenthos and finally the demersal fish component (with 534, 241, 115 and 86 subzones with data, respectively, Table 1). The great majority of the data (70%) was concentrated within continental shelf waters up to 200 m. Total BV maps and hotspot analysis per ecosystem component are illustrated in Fig. 2.

The valuation map for the bird component (Fig. 2A) clearly shows the high ornithological BV of the entire Portuguese coastal zone. High and very high values were distributed along the coast, mainly at less than 100 m depth in the north and center and up to 200 m depth in the south. In contrast, the southwest coast is characterized by very low to medium values up to the region around Cabo São Vicente, where high values appear again. The hotspot map for the bird BV scores (Fig. 2E) visibly shows this discontinuity of higher values along the southwest coast.

For the demersal fish component, high and very high BV were located mostly outside Aveiro estuary, around the isolines for 100–200 m water depth, and in the southwest at deeper depths of around 300 m. However, most of the high and very high BV were concentrated in the south region between 100–200 m (Fig. 2B and F). Sampling effort in 2008 was identical for the entire study area, and data availability depended on the location of the 88 trawled stations.

For the macrobenthos, sampling stations were evenly distributed along the west coast of Portugal but placed in closer proximity in the south coast. The valuation and hotspot map show a distribution of higher valuable areas off Aveiro, Cabo Carvoeiro, south from Setubal bay and in the south region (Fig. 2C and G respectively).

The marine mammals 'component only showed very high BV in the southern region, at a depth of 100–200 m, around São Vicente cape in the west, and near the Spanish border in the east (Fig. 2D and H). High valuable areas were located in the north, around Aveiro region within less than 100 m depth and along the continental slope. Other high valuable areas for this component were present at a shallower depth around Cabo Raso and dispersed around the southwestern and southern

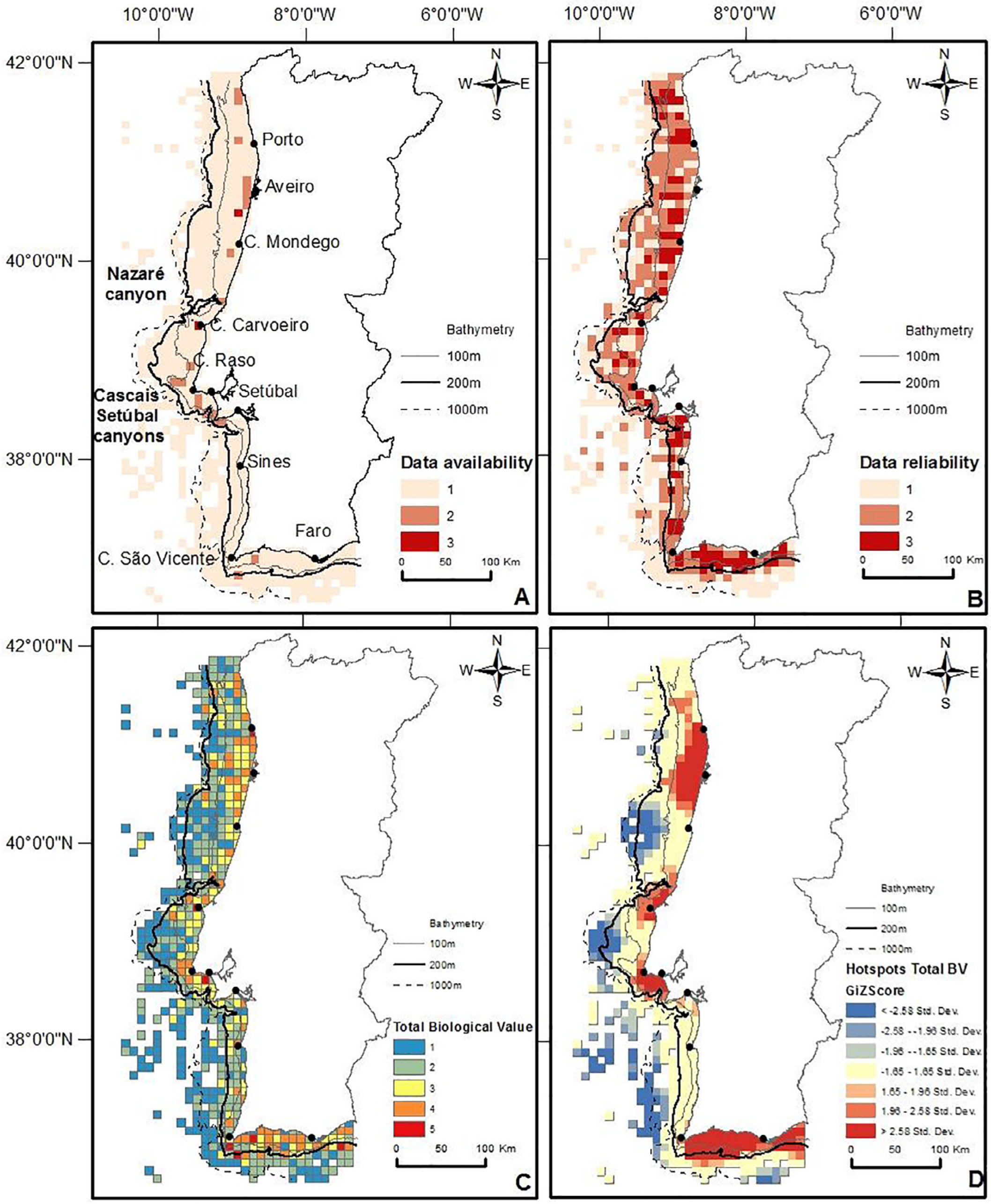


Fig. 3. **A** Total data availability scores (1 = Low, 2 = Medium, 3 = High), **B** Total data reliability scores (1 = Low, 2 = Medium, 3 = High), **C** Total biological value (1 = Very Low, 2 = Low, 3 = Medium, 4 = High, 5 = Very High). **D** Hotspot classification showing z-scores using 95% confidence levels to determine the areas of spatial significance.

region at the continental edge.

The map of total data availability (Fig. 3A), which measures the number of observations/samples in each subzone, shows a quite homogeneous distribution in the study area, with the great majority (96%) of the grid cells containing the same magnitude of available data. Even though data reliability per ecosystem component was very high for the great majority of subzones with data (Supplementary information, Figs. S.2–S.5), the different coverage and sampling effort of the datasets caused the reliability (proportion of assessment questions that could be answered by subzone) of the total BV (Fig. 3B) to oscillate between low (48%), medium (37%) and high (15%). The Total BV map for the whole study area is shown in Fig. 3C. Very low, low, medium, high and very high value areas covered 36%, 35%, 18%, 10% and 1% of the study area respectively. Notably, most of the higher BV scores were consistently located near the coastal zone, in shallower areas. In fact, low and very low values cover 90% of the total study area comprised zones of higher bathymetry (> 100 m). When we look at the results within less than 100 m depth, high and very high BV cover almost 25% of the area, dispersed along the coast, with predominance in the north, center and south regions.

The hotspot analysis for the total BV identified four main hotspot zones of significantly high biological value inside the continental shelf waters; off Aveiro and expanding to the north, off Cabo Carvoeiro, the region off Cabo Raso and Setúbal bay up to Arrábida bay, and covering the majority of the south region (Fig. 3D).

When matching up the reliability indices with the total BV, we found that 70% of the lowest BV, 22% of the high and 38% of the highest total BV have low reliability (Fig. 4). This is caused when the scored subzones comprise information from only one component (out of 4). However, it is important to notice that reliability was higher in

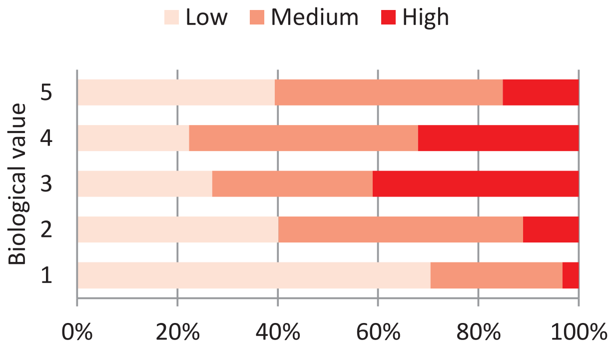


Fig. 4. Reliability of the total BV scores.

coastal areas; in areas shallower than 100 m depth, medium and high reliability scores covered 43% and 33% of the area respectively.

Spearman coefficient of determination (r^2) demonstrated the magnitude of the association between individual components BV and the total BV. As expected, each component's score was significantly positively correlated with the total score. The bird component, which delivered the highest amount of data for the analysis, explained most of the trends detected in the total BV scores contributing to 64% of the variation in the total scores, followed by macrobenthos (21%), mammals (15%) and fish (5%) (Table 1).

3.2. *Spatial overlaps*

3.2.1. *Conservation areas*

Marine SPAs in mainland Portuguese continental waters are illustrated in Fig. 5A. The spatial overlap of the total BV with the marine fraction of the SPAs can be seen in Fig. 5B. 3% of the total area of very low, 16% of the low, 29% of the medium, 28% of the high and 20% of very high total BV are contained inside currently designated SPAs. Concerning individual SPAs, the percentage coverage of total BV can be seen in Fig. 6. Very high BV areas were only included in Costa Sudoeste, Cabo Raso and Ilhas Berlengas and with very low percentage (3–5% Fig. 6). Ria de Aveiro was the SPA with the largest percentage of high BV areas included (52%) followed by Cabo Raso, Ilhas Berlengas, Costa Sudoeste, Aveiro/Nazaré and Ría Formosa (25, 18, 18 16 and 15% respectively; Fig. 6). Cabo Espichel included only low and medium values (18 and 82% respectively), and in all the SPAs but Cabo Espichel and Aveiro low and very low values make up more than 40% of the area protected (40–60%; Fig. 6). Fig. 5C shows the spatial overlap of the hotspot analysis for the total BV and the SPAs and proposed SCIs. It shows that the two BV hotspot areas located in the central region are totally included inside the Ilhas Berlengas and Cabo Raso SPAs. The hotspot around Aveiro expands much further beyond the Ria de Aveiro and Aveiro/Nazaré SPA, being overlapped with the northern part of the proposed Maceda-Praia da Vieira SCI. The hotspot located in the southern region is outside any designated SPA with very limited overlap with Costa Sudoeste SPA around Cabo São Vicente. Yet, the proposed SCI of Costa Sudoeste does cover an important area of the west side of the southerly BV hotspot but the easternmost part falls outside any designated or proposed conservation area.

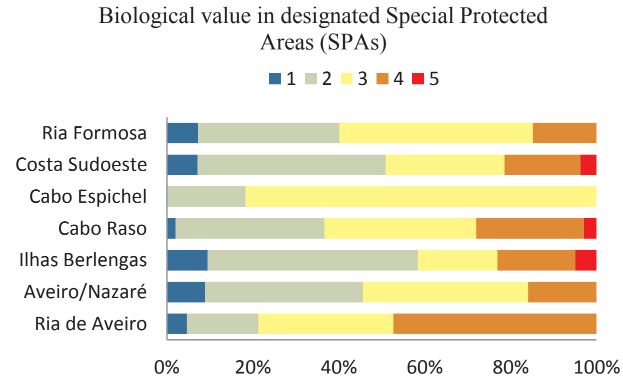


Fig. 6. Stacked graph illustrating the total biological value within Portuguese continental marine SPAs.

3.2.2. *Habitat maps*

The EUSeaMap broad-scale seabed substrate map (Fig. 7A) and biological zone (Fig. 7B) were selected for this analysis. The spatial overlap of the total BV and substrate map resulted in each subzone being defined by a predominant substrate type and biological zone (in terms of total grid cell area). The substrate type was responsible for significant differences in the total BV ($F = 3.104$, $p = 0.00091$, Fig. 8), with a gradient on BV values from coarser to fine sediments. Regarding the biological zone, we analyzed both individual components and the total BV (Fig. 9). For the total BV, higher scores were found in the infralittoral and circalittoral, when compared to deep circalittoral and

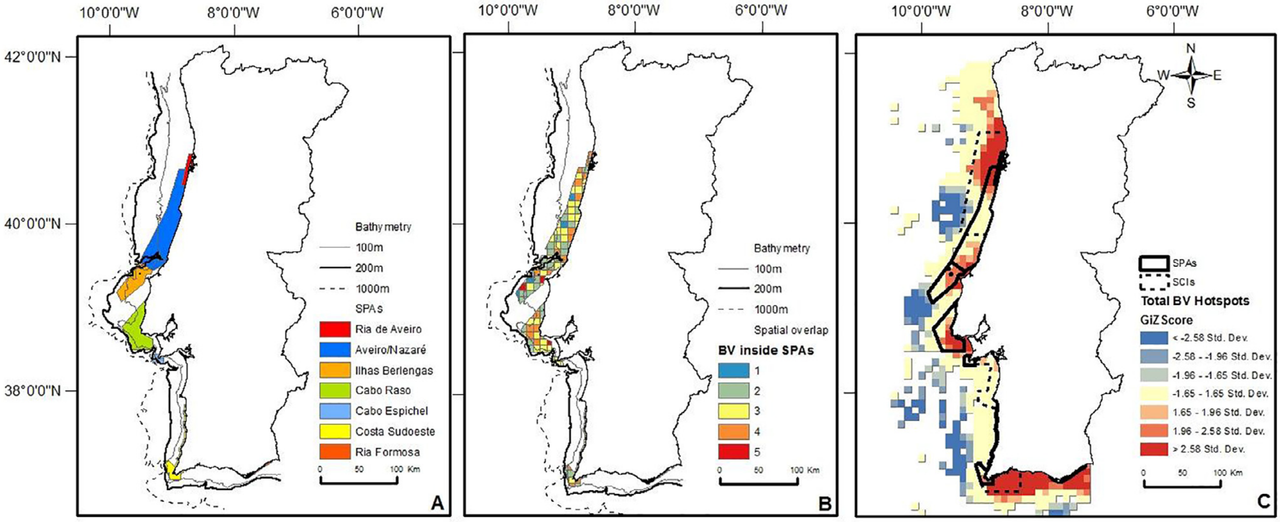


Fig. 5. A Marine Special Protected Areas (SPAs): Ria de Aveiro, Aveiro-Nazaré, Ilhas Berlengas, Cabo Raso, Cabo Espichel, Costa Sudoeste and Ria Formosa. B Spatial overlap of the total BV with SPAs. C Spatial overlap of the total BV hotspot analysis with SPAs and recently proposed marine Sites of Community Importance (SCIs, from north to south: Maceda-Praia da Vieira, Costa de Setúbal and Costa Sudoeste).

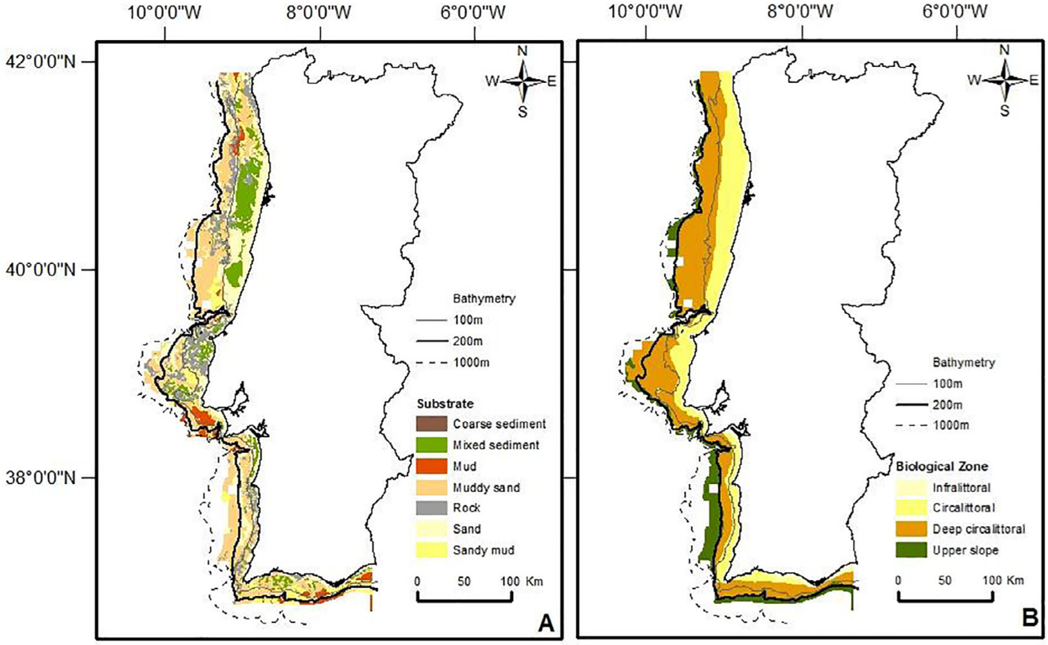


Fig. 7. EUSeaMap broad-scale seabed habitat maps for the Portuguese continental shelf waters: **A** Substrate type layer and **B** Biological zone layer.

upper slope ($F = 25.180$, $p = 0.00000$). This trend was observed in all components, with some deviations, although significant differences were only found in the birds BV ($F = 28.214$, p $p < 0.001$) and macrobenthos BV ($F = 3.193$, $p = 0.026423$).

4. Discussion

This study not only confirms and matches previously identified valuable areas for protection (N2000s sites, especially in the northern and central regions, around Aveiro, Cabo Carvoeiro, and Cabo Raso), but also highlights the value of currently unprotected sites, mainly north of Aveiro and in the southern region. It also describe patterns of biological value consistent with the physical and biological oceanography and local hydrodynamics of the continental Portuguese coast.

4.1. BV per ecosystem component

The bird component BV hotspot map showed significantly valuable areas in the southern region and along the western northern and central sector, mostly in the widest parts of the continental shelf. Similar areas, particularly in the northern and central zones, have already been defined as important bird areas (IBAs, Ramirez et al., 2008) and recently, Araújo et al. (2017) underlined their significance for the critically endangered Balearic shearwater *Puffinus mauretanicus*, an ecologically significant species. These areas are strongly influenced by seasonal upwelling patterns and high productive waters, determined by the bathymetry, coastal morphology, and local wind conditions (Relvas et al., 2007).

For the macrobenthos component, BV scores showed a heterogeneous gradient along the shelf, with high BV areas found off the

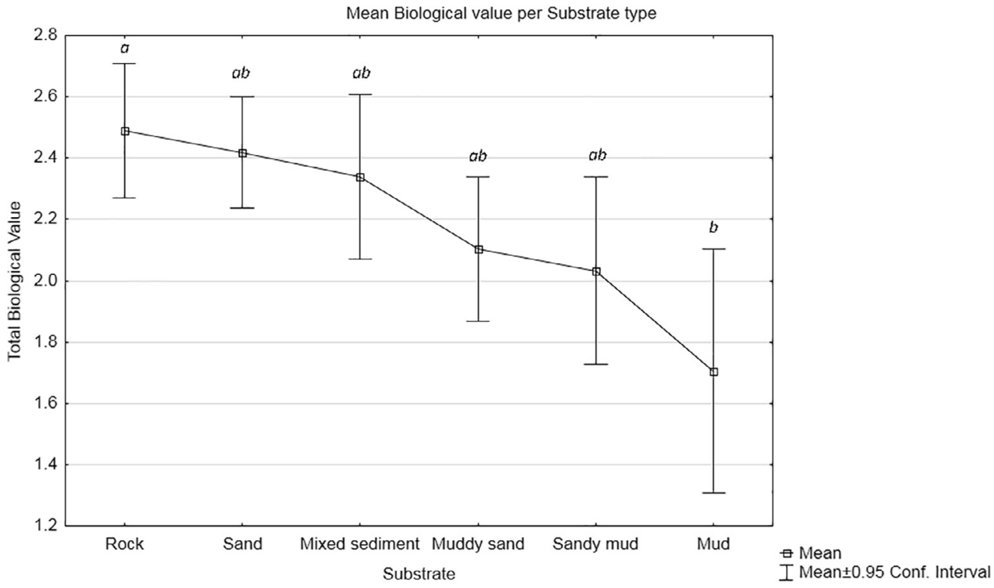


Fig. 8. Mean total BV per substrate type. Bars represent means ± 0.95 Confidence interval. Letters above bars indicate homologous groups after a Tukey HSD test ($p < 0.05$).

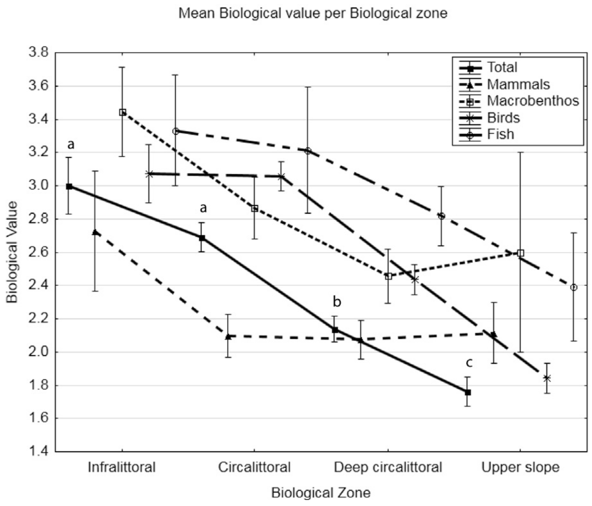


Fig. 9. Mean total BV per biological zone. Bars represent means ± 0.95 Confidence interval. Letters above Total BV bar indicate homologous groups after a Tukey HSD test ($p < 0.05$).

Aveiro, around Cabo Carvoeiro, south from Setubal bay and in the south region, with a hotspot around the Cabo Carvoeiro and Berlengas area, and in the southern region. An analysis of the diversity and distribution patterns of the soft-bottom macrofauna communities using the same macrobenthos dataset also exposed these locations as having high macrofauna abundance, high alpha and Shannon–Wiener diversity and high Pielou evenness indices (Martins et al., 2013). The authors identified depth range, hydrodynamic regime, sediment grain-size and total organic matter content as the variables which best related to the macrofauna distribution patterns.

Highest BV for the demersal fish component were found in the water depths of around 100–200 m in the north shelf, in the southwest at depths of around 300 m and in the south between 100–200 m. Differences in groundfish species assemblages have been observed in other studies, showing a north–south biological discontinuity related to shelf bathymetry, coastal morphology and oceanography along the northern and southern parts of the shelf (Gomes et al., 2001, Sousa et al., 2005). Similar to Sousa et al. (2006), we found lower species richness to the north and higher to the south (see Supplementary information Fig. S.3–F). However, alike the macrobenthos results, there was generally high variability and patchy distribution in demersal fish BV scores along the study area. This is probably the result of two main factors. Firstly, the complex topography and the heterogeneous distribution of substrate types (Martins et al., 2012) is known to influence the structure and diversity of benthic species assemblages. Secondly, there was a clear limitation in the spatial and temporal resolution of the available macrobenthos and demersal fish database. Although survey sampling had a reasonable coverage along the whole study area, single-year databases do not reflect inter-annual and seasonal changes and thus too short to draw safe conclusions about biological value patterns. For this reason, it is possible that some BV scores may be an artifact due to insufficient sampling in the area and it will take greater sampling intensity, both temporally and spatially, to detect more consistent trends in species distributions, and local BV.

The marine mammals' and sea turtles' component only showed very high BV in the southern region, at a depth of 100–200 m, around São Vicente cape in the west, and near the Spanish border in the east. Some high valuable areas were located off Aveiro, at a shallower depth around Cabo Raso and patchily scattered around the southwestern and southern region at the continental edge.

As most studies focus on localized surveys on marine mammal's occurrence, distribution and interaction with fisheries, there is limited information on the overall distribution along the mainland Portuguese shelf waters. The distribution of dolphinids is mainly linked with topographic features such as sheltered bays, submarine canyons and major estuaries, which drive highly productive surface water and input of nutrients (Brito Cristina et al., 2009; Martinho et al., 2015). The southern region, which showed the highest marine mammal's BV values, has already been recognized as an important area for cetaceans (Castro et al., 2013) and specifically for the presence of baleen whales (Laborde et al., 2015).

Ongoing studies, such as the annual aerial campaigns developed within the Life+ MARPRO project (LIFE09 NAT/PT/000038) constitute the first standardized dedicated effort to assess large scale marine mammal abundance and distribution for the entire Portuguese Exclusive Economic Zone. These efforts greatly improve the quantity and quality of sighting records, overcoming the methodological constrain described for the marine mammal database used here.

4.2. Total BV and biodiversity hotspots

The total BV results showed higher scores consistently located near the coastal zone. Regarding data availability, and despite the study area showing relatively low data availability, the map showed a quite homogeneous distribution of scores, with higher data availability scattered in some coastal grid cells in the northern and central regions. This means that most grid cell scores were based on low number of samples/observations for each ecosystem component, highlighting the need to increase sampling coverage during national monitoring surveys. Data reliability showed lower scores mainly outside the 200 m bathymetric zone in the western coast and higher values at the coastal fringe. High reliability scores indicate high number of ecosystem components in each grid cell analyzed and reduces subjectivity of the total result. High and very high BV and medium to high reliability characterized the coastal area up to 100 m depth.

The hotspot analysis identified four main areas: around Aveiro, near Cabo Carvoeiro, south of Cabo Raso, and covering the majority of the southern region. While there are regional and national studies confirming the importance of these areas for individual ecosystem components as aforementioned, there are no published evidences on marine biodiversity patterns using a wide range of taxonomic groups at a national scale. The hotspot approach used here does not discard other areas in need of protection, but it may assist in setting priorities to define crucial areas in conservation strategies for diverse global biota (Myers et al., 2000).

These hotspots seem to coincide with large-scale topographic and oceanographic characteristics which can influence biodiversity and affect the dynamics of the whole ecosystem. The heterogeneous coastline orientation, prominent capes, submarine canyons, large estuaries and river discharges, interacting with mesoscale features, such as fronts, eddies and upwelling areas, result in complex water circulation and seasonal high productivity (see Relvas et al., 2007 for a review on the physical oceanography of the western Iberia ecosystem). These traits are particularly important in the northern and central zone, where the northerly winds are more stable and the wide and lower shelf results in a more persistent and homogeneous upwelling. This fact might explain the higher BV in the northern and central area, when compared with the southwestern sector.

A positive BV gradient was found from muddy to rocky substrates, showing substrate type as an important factor for the BV distribution. Habitat complexity and sediment types have been referred as physical surrogates for biodiversity patterns (McArthur et al., 2009). We also detected higher BV found in the infra and circalittoral biological zones, reflecting a depth gradient in the BV over the study area. The coastal areas were associated with the highest BV, similar to previous studies applying the same protocol (Derous et al., 2007c; Pascual et al., 2011; Vanden Eede et al., 2014).

4.3. Limitations and opportunities

4.3.1. Spatial and temporal scale

Total data availability was estimated as low in most of the study area, meaning a limited number of observations/samples per grid cell. This constraint was particularly restrictive for the relatively immobile macrobenthos component, as the entire grid cell was characterized by a single 0.1 m^2 grab sample. Although the grid cell size might represent a good compromise for mobile components, that is not the case for less mobile and sessile benthic fauna. Using smaller grid cells for such components would be more representative of the associated habitat and together with greater spatial sampling efforts, would stand for more realistic BV of the benthic communities, and consequently total BV patterns.

The temporal scale limitation, as mentioned earlier for the macrobenthos and demersal fish component, is also of great importance, since one year databases can not reflect the inter-annual and seasonal differences which characterize biological systems, particularly in upwelling areas. So, it is important to recognize that we have applied this protocol given the accessible national biological datasets with sufficient spatial coverage and sampling effort at the time of this study and our analysis should be revised and updated as new relevant data becomes available.

4.3.2. Ecosystem components

The addition of spatial data on the distribution and abundance of other important marine ecosystem components, such as pelagic fish, phytoplankton and zooplankton will be crucial to uncover key patterns in the water column and the surface waters. Qualitative and quantitative studies of the phytoplankton distribution and abundance on the Portuguese continental shelf revealed strong seasonal variability at regional and local scales, mainly related to water column stratification, nutrient availability and intensity and persistence of upwelling conditions (Moita, 2001).

Also, given the size of the subzones and nature of the databases, our results fail to provide a complete analysis of the important biological communities at the intertidal and shallow subtidal coastal zones, composed of valuable habitat-forming and engineering species. For this reason, it would be important to repeat this exercise at a smaller spatial scale, including different coastal habitats, such as transitional waters, seagrass and kelp beds, saltmarshes, rocky and sandy shores capture the structure and function of littoral ecosystems. While most data were simply not available, other could not be used due to insufficient spatial coverage and/or lack of abundance information.

Finally, and given the extensive nature of the temporal and spatial data, with multiple ecosystem components and sampling strategies, identifying and quantifying the major determinants of uncertainty in the datasets was not feasible. Even though we used reliability score to measure the “trustworthiness” of the data, the fact that uncertainty (errors in the source data) were not accounted for may contribute to some biased results about specific species and areas.

4.3.3. Opportunities

The flexibility of the protocol permitted the remodeling of algorithms to include local knowledge on ecosystem components. Moreover, the set of assessment questions can be adapted to different processes and organizational levels of biodiversity as proposals for new valuation criteria emerge. This way, the method allows for future refinement in the choice of biological-based metrics to define the different facets and dimensions of biological systems (Pereira et al., 2013).

4.4. Overlap with conservation areas

This study shows that there is a good agreement between the spatial coverage of high BV and hotspots with the continental Portuguese SPAs. Almost half of the total area containing high and very high BV fell inside currently designated SPAs. Even though the SPAs have been designated to safeguard the habitats of migratory and threatened birds under the Birds Directive, it is relevant to compare its location with our integrative biological hotspots. Being important top predators, seabirds have been described as good indicators of the health of the marine environment, as they travel or forage in productive marine hotspots (Parsons et al., 2008). This way, seabird’s distributions can act as proxies for identifying priority sites for conservation (Harris et al., 2007; Hooker and Gerber, 2004).

Importantly, our results also show that the proposed SCIs can complement the protection status of valuable areas. However, the main spatial disagreement was observed in the southern region, which showed very high BV scores for all ecosystem components separately and for total BV, but is currently under little protection status. At present, the only designated protected area in the south region is the area surrounding the Cabo São Vicente and the Ria Formosa SPA and Natural Park, an inter-tidal meadow lagoon with very limited coverage of coastal and deeper habitats. The proposed SCI of Costa Sudoeste covers an important area at the westernmost side of the southern hotspot, leaving the eastern southern side under no current or proposed conservation status.

In this way, our study supports the location of existing SPAs and proposed SCIs as important sites for the conservation of valuable areas and suggests the need to extend the protection along the southern region. Management plans should establish structured and evidence-based instruments to guide managers to make sound decisions in accordance with the ecological needs and conservation of vulnerable habitat types and species.

4.5. Management implications

At the European level, the MSFD directive refers to biodiversity as a key indicator to achieve “Good Environmental Status”, by stating *“the quality and occurrence of habitats and the distribution and abundance of species should be in line with prevailing physiographic, geographic and climatic conditions”*. Recently, Portugal has been used as a case study for a large scale marine biodiversity assessment under the MSFD (Uusitalo et al., 2016). The overall results exposed Portugal with a “Moderate” environmental status (on a scale of 5, from Poor to High) and adverted for major knowledge gaps in species distribution and areal coverage.

At the national level, Portugal has already developed an initial assessment of the current environmental status of national marine waters with a comprehensive biological characterization of marine waters under the national jurisdiction (MAMAOT, 2012). It was based on the marine biological valuation protocol and covered broad evaluation areas up to 200 nautical miles using data on phytoplankton, zooplankton, macrobenthos, bivalves, cephalopods, crustaceans, fish, birds and mammals. This assessment initiative analyzed each component separately, using large scale subzones and it did not generate a total BV map across components. The results concluded on a “good environmental status” for the major habitats (coastal and pelagic) and for the majority of the functional groups analyzed. Even though these general studies are crucial to attend to international policy demands, the scanty spatial resolutions of the results are a major limiting factor when dealing with the imminent pressure and impacts of local maritime exploitation. The rise of the blue growth economy is rushing countries to make smaller scale decisions on the spatial allocation of maritime activities. In this regard, the marine biological valuation tool presented here represents a clear advantage in relation with the MSFD approaches in terms of spatial resolution of the environmental metrics. Instead of providing a single “status” for major habitats, ecosystems components and biodiversity, it provides a multi-metric ecological indicator, with a relative scoring system of intrinsic biological value of small subzones over the entire study area.

In Portugal, the legally binding MSP is responsible for dealing with the growing and competing demands for maritime space, such as oil and gas exploration, fisheries, seabed mining, maritime shipping, aquaculture, coastal and maritime tourism, marine biotechnology, ocean energy and environmental protection. A recent study by Fernandes et al. (2017) showed that the continental Portuguese coastal space is experiencing high cumulative impacts caused by current activities, and alerted for the need to improve environmental assessment tools. Interestingly, all the hotspots for the total BV detected in our study coincide with areas where anthropogenic impacts (mainly fisheries and pollution) were also greater. The authors also alerted for the fact that nature conservation areas considered in the ongoing MSP plan (INAG, 2012) were still prone to exploration, such as fishing, aquaculture, oil, wave and offshore wind inspection or sand and gravel extraction. The environmental section of the MSP plan further states that "the information currently available to assess marine ecosystems and biodiversity as well as the cultural values associated with the sea is scarce and fragmented". Consequently, if marine policies are not built upon scientifically-recognized principles on the functioning of biological communities, the ecosystem based approach underlying MSP policies might be compromised. In this sense, biological valuation maps can highlight valuable areas useful within the scope of MSP. Also, it allows for the integration of biodiversity with socio-economic and best expert judgment criteria to assist in space-use conflicts in an appropriate spatial scale.

This study has proved useful to outline the importance of allowing scientists the opportunity to access and link scattered data for informative biological valuations, essential to assist science reproducibility and to minimize biases in policy development. In this sense, we advocate for the need to have environmental researchers, computer scientists and policy makers working together on the creation and maintenance of a national marine biodiversity database with up-to-date information on the distribution and abundance of marine organisms. Finally, this approach should stimulate discussion among Portuguese scientists, stakeholders and managers involved in the Natura 2000 network, MSFD and MSP process on value-based criteria to define areas of biological importance to safeguard environmental sustainability in "an ocean of opportunities".

5. Conclusions

The application of the marine biological valuation and hotspot analysis to the Portuguese continental shelf waters resulted in the recognition of four major biologically valuable regions, despite temporal and spatial data limitation. These areas matched topographic and physical oceanographic attributes known to influence biodiversity, such as coastline orientation, prominent capes, submarine canyons, large estuaries, habitat type and wind-induced upwelling areas. The hotspots fall within the boundaries of N2000s designated SPAs and proposed SCIs, except in the easternmost part of the southern hotspot. Quantitative-based approaches such as the one presented here may assist in guiding management plans and decisions to safeguard local biological value and defining priority areas for conservation at the scale of tens of kilometers, useful within the scope of MSP.

Acknowledgments

The authors thank and acknowledge the following individuals, institutions and projects for support, logistic assistance and data sharing: Maria de Jesus Fernandes, Director of the Departamento de Conservação da Natureza e Florestas de Lisboa e Vale do Tejo of the Instituto de Conservação da Natureza e Florestas, Ana Meirinho e Pedro Correia Rodrigues (SPEA), Lia Laporta, LIFE IBAs Marinhas (LIFE04NAT/PT/000213) supported by the LIFE Programme of the EU and FAME (project n.° 2009-1/089) supported by the Atlantic Area Programme and the Flemish contribution to LifeWatch, supported by the Research Foundation Flanders (FWO), Financial support was allocated by FCT under the COMPETE Programme, which includes components from the European Regional Development Fund and from the Ministério da Ciência, Tecnologia e Ensino Superior. Thanks are due, for the financial support, to CESAM (UID/AMB/50017/2013), supported through national funds by FCT/MCTES and the co-funding by the FEDER (POCI-01-0145-FEDER-007638), within the PT2020 Partnership Agreement and Compete 2020. I.G.'s PhD work was supported by a MARES grant. MARES is an Erasmus Mundus Joint Doctorate programme coordinated by Ghent University (FPA 2011-0016). S.P. was supported by Fundação para a Ciência e Tecnologia (FCT), through the strategic project UID/MAR/04292/2013 granted to MARE. L.P. was supported by a postdoctoral fellowship from Xunta de Galicia, Spain (POS-B/2016/032). J. B-P. was funded by the Calouste Gulbenkian Foundation, through the project "The Economic Valuation and Governance of Marine and Coastal Ecosystem Services" (MCES) (BPD/UI88/6454/2014).

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2018.05.040.

References

Airamé, S., Dugan, J.E., Lafferty, K.D., Leslie, H., McArdle, D.A., Warner, R.R., 2003. Applying ecological criteria to marine reserve design: a case study from the California channel islands. Ecol. Appl. 13, S170–S184. http://dx.doi.org/10.2307/3100006.

Angulo-Valdés, J.A., Hatcher, B.G., 2010. A new typology of benefits derived from marine protected areas. Mar. Policy 34, 635–644. http://dx.doi.org/10.1016/j.marpol.2009.12.002.

Araújo, H., Bastos-Santos, J., Rodrigues, P.C., Ferreira, M., Pereira, A., Henriques, A.C., Monteiro, S.S., Eira, C., Vingada, J., 2017. The importance of Portuguese Continental Shelf Waters to Balearic Shearwaters revealed by aerial census. Mar. Biol. 164, 55. http://dx.doi.org/10.1007/s00227-017-3089-x.

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., Silliman, B.R., 2011. The value of estuarine and coastal ecosystem services. Ecol. Monogr. 81, 169–193. http://dx.doi.org/10.1890/10-1510.1.

Bartkowski, B., Lienhoop, N., Hansjürgens, B., 2015. Capturing the complexity of biodiversity: a critical review of economic valuation studies of biological diversity. Ecol. Econ. 113, 1–14. http://dx.doi.org/10.1016/j.ecolecon.2015.02.023.

Bräuer, I., 2003. Money as an indicator: to make use of economic evaluation for biodiversity conservation. Agric. Ecosyst. Environ. 98, 483–491. http://dx.doi.org/10.1016/S0167-8809(03)00107-5.

Cristina, Brito, Nina, Vieira, Erica, Sá, Inês, Carvalho, 2009. Cetaceans' occurrence off the west central Portugal coast: a compilation of data from whaling, observations of opportunity and boat-based surveys. J. Mar. Anim. Ecol. 2, 10–13.

Brooks, T.M., Mittermeier, R.A., Da Fonseca, G.A.B., Gerlach, J., Hoffmann, M., Lamoreux, J.F., Mittermeier, C.G., Pilgrim, J.D., Rodrigues, A.S.L., 2006. Global Biodiversity Conservation Priorities 58. doi: 10.1126/science.1127609.

Cafaro, P., Primack, R., 2014. Species extinction is a great moral wrong. Biol. Conserv. 170, 1–2.

Calado, H., Ng, K., Johnson, D., Sousa, L., Phillips, M., Alves, F., 2010. Marine spatial planning: lessons learned from the Portuguese debate. Mar. Policy 34, 1341–1349. http://dx.doi.org/10.1016/j.marpol.2010.06.007.

Callicott, J.B., 2006. Conservation values and ethics. In: Meffe, G.K., Caroll, C.R. (Eds.), Principles of Conservation Biology. Sinauer Associates Inc., Sunderland, MA, pp. 111–135.

Camphuysen, K.C.J., Garthe, S., 2004. Recording foraging seabirds at sea: standardised recording and coding of foraging behaviour and multi-species foraging associations. Atl. Seabirds.

Carr, M.H., Neigel, J.E., Estes, J.A., Andelman, S., Warner, R.R., Largier, J.L., 2003. Comparing marine and terrestrial ecosystems: implications for the design of coastal marine reserves. Ecol. Appl. S90–S107. http://dx.doi.org/10.2307/3100000.

Castro, J., Cid, A., Fonseca, C., Galego, S., Laborde, M.I., 2013. Cetacean monitoring in the South Coast of mainland Portugal. In: 20th Biennial Conference on the Biology of Marine Mammals. Dunedin, New Zealand.

Chan, K.M.A., Balvanera, P., Benessaiah, K., Chapman, M., D'iaz, S., Gómez-Baggethun, E., Gould, R., Hannahs, N., Jax, K., Klain, S., Luck, G.W., Mart'in-López, B., Muraca, B., Norton, B., Ott, K., Pascual, U., Satterfield, T., Tadaki, M., Taggart, J., Turner, N., 2016. Opinion: why protect nature? Rethinking values and the environment. Proc. Natl. Acad. Sci. U.S.A. 113, 1462–1465. http://dx.doi.org/10.1073/pnas.1525002113.

Chaves, C., 2008. Demersal de Outono Setembro 2008. Relatórios de Campanha, Instituto Português do Mar e da Atmosfera, 20p.

Christie, P., Bennett, N.J., Gray, N.J., Wilhelm, A., Lewis, N., Parks, J., Ban, N.C., Gruby, R.L., Gordon, L., Day, J., Taei, S., Friedlander, A.M., 2017. Why people matter in ocean governance: incorporating human dimensions into large-scale marine protected areas. Mar. Policy 84, 273–284.

Costanza, R., D'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997.

The value of the world's ecosystem services and natural capital. Nature 387, 253–260. http://dx.doi.org/10.1038/387253a0.

Daniel, T.C., Muhar, A., Arnberger, A., Aznar, O., Boyd, J.W., Chan, K.M.A., Costanza, R., Elmqvist, T., Flint, C.G., Gobster, P.H., Grêt-Regamey, A., Lave, R., Muhar, S., Penker, M., Ribe, R.G., Schauppenlehner, T., Sikor, T., Soloviy, I., Spierenburg, M., Taczanowska, K., Tam, J., von der Dunk, A., 2012. Contributions of cultural services to the ecosystem services agenda. Proc. Natl. Acad. Sci. U.S.A. 109, 8812–8819. http://dx.doi.org/10.1073/pnas.1114773109.

De Groot, R.S., Wilson, M.A., Boumans, R.M.J., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecol. Econ. 41, 393–408. http://dx.doi.org/10.1016/S0921-8009(02)00089-7.

Deneudt, K., Institute, Flanders Marine, 2013. BVMtool: LifeWatch computational tool for marine Biological Valuation Mapping. VLIZ. http://dx.doi.org/10.14284/307.

Derous, S., Agardy, T., Hillewaert, H., Hostens, K., Jamieson, G., Lieberknecht, L., Mees, J., Moulaert, I., Olenin, S., Paelinckx, D., Rabaut, M., Rachor, E., Roff, J., Willem, E., Stienen, M., Wal, J.T. Van Der, Lancker, V. Van, Verfaillie, E., Vincx, M., Degraer, S., 2007a. A concept for biological valuation in the marine environment*. Oceanologia 49, 99–128.

Derous, S., Austen, M., Claus, S., Daan, N., Dauvin, J., Deneudt, K., 2007b. Building on the Concept of marine biological valuation with respect to translating it to a practical protocol: viewpoints derived from a joint ENCORA-MARBEF initiative. Oceanologia 49, 1–8.

Derous, S., Austen, M., Claus, S., Daan, N., Dauvin, J.-C., Deneudt, K., Depestele, J., Desroy, N., Heessen, H., Hostens, K., Husum Marboe, A., Lescrauwaet, A.-K., Moreno, M.P., Moulaert, I., Paelinckx, D., Rabaut, M., Rees, H., Ressurreição, A., Roff, J., Santos, P.T., Speybroeck, J., Willem, E., Stienen, M., Tatarek, A., Hofstede, R. Ter, Vincx, M., Zarzycki, T., Degraer, S., 2007c. Building on the concept of marine biological valuation with respect to translating it to a practical protocol: viewpoints derived from a joint ENCORA–MARBEF initiative* Marine biological valuation Ecological criteria Intrinsic value. Oceanologia 49, 1–8.

Doak, D.F., Bakker, V.J., Goldstein, B.E., Hale, B., 2014. What is the future of conservation? Trends Ecol. Evol. 29, 77–81. http://dx.doi.org/10.1016/j.tree.2013.10.013.

Dunn, D.C., Ardron, J., Bax, N., Bernal, P., Cleary, J., Cresswell, I., Donnelly, B., Dunstan, P., Gjerde, K., Johnson, D., Kaschner, K., 2014. The convention on biological diversity's ecologically or biologically significant areas: origins, development, and current status. Mar. Policy 49, 137–145. http://dx.doi.org/10.1016/J.MARPOL.2013.12.002.

Eken, G., Bennun, L., Brooks, T.M., Darwall, W., Fishpool, L.D.C., Foster, M., Knox, D., Langhammer, P., Matiku, P., Radford, E., Salaman, P., Sechrest, W., Smith, M.L., Spector, S., Tordoff, A., 2004. Key biodiversity areas as site conservation targets. Bioscience 54, 1110–1118. http://dx.doi.org/10.1641/0006-3568(2004)054[1110:kbaasc]2.0.co;2.

Fanny, B., Nicolas, D., Sander, J., Erik, G.-B., Marc, D., 2015. How (not) to perform ecosystem service valuations: pricing gorillas in the mist. Biodivers. Conserv. 24, 187–197. http://dx.doi.org/10.1007/s10531-014-0796-1.

Fernandes, M., Esteves, T.C., Oliveira, E.R., Alves, F.L., 2017. How does the cumulative impacts approach support Maritime Spatial Planning? Ecol. Indic. 73, 189–202. http://dx.doi.org/10.1016/J.ECOLIND.2016.09.014.

Fishpool, L.D.C., Heath, M.F., Waliczky, Z., Wege, D.C., Crosby, M.J., 1998. Important Bird Areas criteria for selecting sites of global conservation significance, in: Adams, N.J., Slotow, R.H. (Eds.), Int. Ornith. Cong. Durban, p. 428.

Forero, C.E., 2007. Biological valuation of the marine environment, the netherlands. Vrije Universiteit Brussel. (Belgium).

Frazão Santos, C., Domingos, T., Ferreira, M.A., Orbach, M., Andrade, F., 2014. How sustainable is sustainable marine spatial planning? Part I—Linking the concepts. Mar. Policy 49, 59–65. http://dx.doi.org/10.1016/j.marpol.2014.04.004.

Frazão Santos, C., Orbach, M., Calado, H., Andrade, F., 2015. Challenges in implementing sustainable marine spatial planning: the new Portuguese legal framework case. Mar. Policy 61, 196–206. http://dx.doi.org/10.1016/j.marpol.2015.08.010.

Getis, A., Ord, J.K., 1992. The analysis of spatial association by use of distance statistics. Geogr. Anal. 24, 189–206. http://dx.doi.org/10.1111/j.1538-4632.1992.tb00261.x.

Golden, J.S., Virdin, J., Nowacek, D., Halpin, P., Bennear, L., Patil, P.G., 2017. Making sure the blue economy is green. Nature. http://dx.doi.org/10.1038/s41559-016-0017.

Gomes, M.C., Serrão, E., De Fátima, M., Gomes, B., Serrão, M.C., Gomes, M.C., 2001. Spatial patterns of groundfish assemblages on the continental shelf of Portugal. ICES J. Mar. Sci. – ICES J. Mar. Sci. 58. http://dx.doi.org/10.1006/jmsc.2001.1052.

Gómez-Baggethun, E., de Groot, R., Lomas, P.L., Montes, C., 2010. The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. Ecol. Econ. 69, 1209–1218. http://dx.doi.org/10.1016/j.ecolecon.2009.11.007.

Harris, J., Haward, M., Jabour, J., Woehler, E.J., 2007. A new approach to selecting Marine Protected Areas (MPAs) in the Southern Ocean. Antarct. Sci. 19, 189. http://dx.doi.org/10.1017/S0954102007000260.

Hector, A., Bagchi, R., 2007. Biodiversity and ecosystem multifunctionality. Nature 448, 188–190. http://dx.doi.org/10.1038/nature05947.

Hooker, S.K., Gerber, L.R., 2004. Marine reserves as a tool for ecosystem-based management: the potential importance of megafauna. Bioscience 54, 27–39. http://dx.doi.org/10.1641/0006-3568(2004) 054[0027:mraatf]2.0.co;2.

Huxham, M., Emerton, L., Kairo, J., Munyi, F., Abdirizak, H., Muriuki, T., Nunan, F., Briers, R.A., 2015. Applying climate compatible development and economic valuation to coastal management: a case study of Kenya's mangrove forests. J. Environ. Manage. 157, 168–181. http://dx.doi.org/10.1016/j.jenvman.2015.04.018.

INAG, 2012. POEM—Plano de Ordenamento do Espaç o Marítimo, Volume 2 Tomo1: Espacialização (in Portuguese).

Jobstvogt, N., Hanley, N., Hynes, S., Kenter, J., Witte, U., 2014. Twenty thousand sterling under the sea: estimating the value of protecting deep-sea biodiversity. Ecol. Econ. 97, 10–19. http://dx.doi.org/10.1016/j.ecolecon.2013.10.019.

Kenter, J.O., O'Brien, L., Hockley, N., Ravenscroft, N., Fazey, I., Irvine, K.N., Reed, M.S., Christie, M., Brady, E., Bryce, R., Church, A., Cooper, N., Davies, A., Evely, A., Everard, M., Fish, R., Fisher, J.A., Jobstvogt, N., Molloy, C., Orchard-Webb, J., Ranger, S., Ryan, M., Watson, V., Williams, S., 2015. What are shared and social values of ecosystems? Ecol. Econ. 111, 86–99. http://dx.doi.org/10.1016/j.ecolecon.2015.01.006.

Ida, Kubiszewski, Robert, Costanza, Sharolyn, Anderson, Paul, Sutton, 2017. The future value of ecosystem services: global scenarios and national implications. Ecosyst. Serv. 26, 289–301. http://dx.doi.org/10.1016/J.ECOSER.2017.05.004.

Laborde, M. I., Cid, A., Fonseca, C., Castro, J., 2015. Baleen whales in Southern Portugal: new insights. 29th Annual Conference of the European Cetacean Society. Malta.

Laurila-Pant, M., Lehikoinen, A., Uusitalo, L., Venesjärvi, R., 2015. How to value biodiversity in environmental management? Ecol. Indic. 55, 1–11. http://dx.doi.org/10.1016/j.ecolind.2015.02.034.

MAMAOT, 2012. Maritime Strategy for Continent Subdivision (Estrategia Marinhapara a Divisão do Continente). Ministry of Agriculture, Sea, Environment andSpatial Planning (in Portuguese).

Martin-López, B., Iniesta-Arandia, I., Garc'ia-Llorente, M., Palomo, I., Casado-Arzuaga, I., Amo, D.G Del, Gómez-Baggethun, E., Oteros-Rozas, E., Palacios-Agundez, I., Willaarts, B., González, J.A., Santos-Mart'in, F., Onaindia, M., López-Santiago, C., Montes, C., 2012. Uncovering ecosystem service bundles through social preferences. PLoS One 7, e38970. http://dx.doi.org/10.1371/journal.pone.0038970.

Martinho, F., Pereira, A., Brito, C., Gaspar, R., Carvalho, I., 2015. Structure and abundance of bottlenose dolphins (*Tursiops truncatus*) in coastal Setúbal Bay, Portugal. Mar. Biol. Res. 11, 144–156. http://dx.doi.org/10.1080/17451000.2014.894244.

Martins, R., Quintino, V., Rodrigues, A.M., 2013. Diversity and spatial distribution patterns of the soft-bottom macrofauna communities on the Portuguese continental shelf. J. Sea Res. 83, 173–186. http://dx.doi.org/10.1016/J.SEARES.2013.03.001.

Martins, R., Sampaio, L., Quintino, V., Rodrigues, A., 2014. Diversity, distribution and ecology of benthic molluscan communities on the Portuguese continental shelf. J. Sea Res. 93, 75–89. http://dx.doi.org/10.1016/J.SEARES.2013.11.006.

Martins, R., Azevedo, M.R., Mamede, R., Sousa, B., Freitas, R., Rocha, F., Quintino, V., Rodrigues, A.M., 2012. Sedimentary and geochemical characterization and provenance of the Portuguese continental shelf soft-bottom sediments. J. Mar. Syst. 91, 41–52.

McArthur, M.A., Brooke, B., Przeslawski, R., Ryan, D.A., Lucieer, V.L., Nichol, S., McCallum, A.W., Mellin, C., Cresswell, I.D., Radke, L. C. 2009. A Review of Abiotic Surrogates for Marine Benthic Biodiversity. Geoscience Australia, Record 2009/42. Geoscience Australia, Canberra. 61pp.

Mil-homens, M., Stevens, R.L., Cato, I., Abrantes, F., 2007. Regional geochemical baselines for Portuguese shelf sediments. Environ. Pollut. 148, 418–427. http://dx.doi.org/10.1016/j.envpol.2006.12.007.

Moita, M.T., 2001. Estrutura, variabilidade e dinâmica do fitoplâncton na costa de Portugal Continental. PhD thesis. Faculdade de Ciências da Universidade de Lisboa. 272p.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858. http://dx.doi.org/10.1038/35002501.

Nahlik, A.M., Kentula, M.E., Fennessy, M.S., Landers, D.H., 2012. Where is the consensus? A proposed foundation for moving ecosystem service concepts into practice. Ecol. Econ. 77, 27–35. http://dx.doi.org/10.1016/j.ecolecon.2012.01.001.

Oliveira, A., Santos, A.I., Rodrigues, A., Vitorino, J., 2007. Sedimentary particle distribution and dynamics on the Nazaré canyon system and adjacent shelf (Portugal). Mar. Geol. 246, 105–122. http://dx.doi.org/10.1016/j.margeo.2007.04.017.

Parsons, M., Mitchell, I., Butler, A., Ratcliffe, N., Frederiksen, M., Foster, S., Reid, J.B., 2008. Seabirds as indicators of the marine environment. ICES J. Mar. Sci. 65, 1520–1526. http://dx.doi.org/10.1093/icesjms/fsn155.

Pascual, M., Borja, A., Eede, S. Vanden, Deneudt, K., Vincx, M., Galparsoro, I., Legorburu, I., 2011. Marine biological valuation mapping of the Basque continental shelf (Bay of Biscay), within the context of marine spatial planning. Estuar. Coast. Shelf Sci. 95, 186–198. http://dx.doi.org/10.1016/j.ecss.2011.08.031.

Pendleton, L.H., 1995. Valuing coral reef protection. Ocean Coast. Manage. 26, 119–131. http://dx.doi.org/10.1016/0964-5691(95)00007-O.

Pereira, H.M., Ferrier, S., Walters, M., Geller, G.N., Jongman, R.H.G., Scholes, R.J., Bruford, M.W., Brummitt, N., Butchart, S.H.M., Cardoso, A.C., Coops, N.C., Dulloo, E., Faith, D.P., Freyhof, J., Gregory, R.D., Heip, C., Höft, R., Hurtt, G., Jetz, W., Karp, D.S., McGeoch, M.A., Obura, D., Onoda, Y., Pettorelli, N., Reyers, B., Sayre, R., Scharlemann, J.P.W., Stuart, S.N., Turak, E., Walpole, M., Wegmann, M., 2013. Ecology. Essential biodiversity variables. Science 339, 277–278. http://dx.doi.org/10.1126/science.1229931.

Peterson, M.N., Birckhead, J.L., Leong, K., Peterson, M.J., Peterson, T.R., 2010. Rearticulating the myth of human-wildlife conflict. Conserv. Lett. 3, 74–82. http://dx.doi.org/10.1111/j.1755-263X.2010.00099.x.

Petrosillo, I., Zurlini, G., Corlianò, M.E., Zaccarelli, N., Dadamo, M., 2007. Tourist perception of recreational environment and management in a marine protected area. Landsc. Urban Plan. 79, 29–37. http://dx.doi.org/10.1016/j.landurbplan.2006.02.017.

Polak, O., Shashar, N., 2013. Economic value of biological attributes of artificial coral reefs. ICES J. Mar. Sci. 70, 904–912. http://dx.doi.org/10.1093/icesjms/fst014.

Populus, J., Vasquez, M., Albrecht, J., Manca, E., Agnesi, S., Al Hamdani, Z., Andersen, J., Annunziatellis, A., Bekkby, T., Bruschi, A., Doncheva, V., Drakopoulou, V., Duncan, G., Inghilesi, R., Kyriakidou, C., Lalli, F., Lillis, H., Mo, G., Muresan, M., Salomidi, M., Sakellariou, D., Simboura, M., Teaca, A., Tezcan, D., Todorova, V., Tunesi, L., 2017.

EUSeaMap. A European broad-scale seabed habitat map. doi: 10.13155/49975.

Purvis, A., Hector, A., 2000. Getting the measure of biodiversity. Nature 405, 212–219. http://dx.doi.org/10.1038/35012221.

Ramírez I., P. Geraldes, A. Meirinho, P. Amorim, V. Paiva, 2008. Áreas marinhas importantes para as Aves em Portugal. Projecto LIFE04NAT/PT/000213 – Sociedade Portuguesa Para o Estudo das Aves. Lisboa.

Rego, T., 2007. A Biological Valuation of the Pico e Faial Channel. University of Azores, Portugal. Msc thesis.

Relvas, P., Barton, E.D., Dubert, J., Oliveira, P.B., Peliz, Á., da Silva, J.C.B., Santos, A.M.P., 2007. Progress in Oceanography Physical oceanography of the western Iberia ecosystem: latest views and challenges. Prog. Oceanogr. 74, 149–173. http://dx.doi.org/10.1016/j.pocean.2007.04.021.

Ressurreição, A., Gibbons, J., Dentinho, T.P., Kaiser, M., Santos, R.S., Edwards-Jones, G., 2011. Economic valuation of species loss in the open sea. Ecol. Econ. 70, 729–739. http://dx.doi.org/10.1016/j.ecolecon.2010.11.009.

Roberts, C.M., Branch, G., Bustamante, R.H., Castilla, J.C., Dugan, J., Halpern, B.S., Lafferty, K.D., Leslie, H., Lubchenco, J., McArdle, D., Ruckelshaus, M., Warner, R.R., 2003. Application of ecological criteria in selecting marine reserves and developing reserve networks. Ecol. Appl. 13, 215–228. http://dx.doi.org/10.1890/1051-0761(2003) 013[0215:AOECIS]2.0.CO;2.

Scharks, T., Masuda, Y.J., 2016. Don't discount economic valuation for conservation. Conserv. Lett. 9, 3–4. http://dx.doi.org/10.1111/conl.12234.

Scholte, S.S.K., van Teeffelen, A.J.A., Verburg, P.H., 2015. Integrating socio-cultural perspectives into ecosystem service valuation: a review of concepts and methods. Ecol. Econ. 114, 67–78. http://dx.doi.org/10.1016/j.ecolecon.2015.03.007.

Smith, C., Papadopoulou, N., Sevastou, K., Franco, A., Teixeira, H., Piroddi, C., Katsanevakis, S., Fürhaupter, K., Beauchard, O., Cochrane, S., Ramsvatn, S., Feral, J.-P., Chenuil, A., David, R., Kiriakopoulou, N., Zaiko, A., Moncheva, S., Stefanova, K., Churilova, T., Kryvenko, O. 2014. Report on identification of keystone species and processes across regional seas. Deliverable 6.1, DEVOTES Project. 105 pp + 1 Annex.

Sousa, P., Azevedo, M., Gomes, M.C., 2005. Demersal assemblages off Portugal: mapping, seasonal, and temporal patterns. Fish. Res. 75, 120–137. http://dx.doi.org/10.1016/j.fishres.2005.03.012.

Sousa, P., Azevedo, M., Gomes, M.C., 2006. Species-richness patterns in space, depth, and time (1989–1999) of the Portuguese fauna sampled by bottom trawl. Aquat. Living Resour. 19, 93–103. http://dx.doi.org/10.1051/alr:2006009.

Spash, C.L., 2015. Bulldozing biodiversity: the economics of offsets and trading-in Nature. Biol. Conserv. 192, 541–551. http://dx.doi.org/10.1016/j.biocon.2015.07.037.

Tuya, F., Haroun, R., Espino, F., 2014. Economic assessment of ecosystem services: monetary value of seagrass meadows for coastal fisheries. Ocean Coast. Manage. 96, 181–187. http://dx.doi.org/10.1016/j.ocecoaman.2014.04.032.

Uusitalo, L., Blanchet, H., Andersen, J.H., Beauchard, O., Berg, T., Bianchelli, S., Cantafaro, A., Carstensen, J., Carugati, L., Cochrane, S., Danovaro, R., Heiskanen, A.-S., Karvinen, V., Moncheva, S., Murray, C., Neto, J.M., Nygård, H., Pantazi, M., Papadopoulou, N., Simboura, N., Srėbalienė, G., Uyarra, M.C., Borja, A., 2016. Indicator-based assessment of marine biological diversity-lessons from 10 case studies across the European seas. Front. Mar. Sci. 3, 159. http://dx.doi.org/10.3389/fmars.2016.00159.

Vanden Eede, S., Laporta, L., Deneudt, K., Stienen, E., Derous, S., Degraer, S., Vincx, M., 2014. Marine biological valuation of the shallow Belgian coastal zone: a space-use conflict example within the context of marine spatial planning. Ocean Coast. Manage. 96, 61–72. http://dx.doi.org/10.1016/j.ocecoaman.2014.04.022.

Villa, F., Tunesi, L., Agardy, T., 2002. Zoning marine protected areas through spatial multiple-criteria analysis: the case of the Asinara island national marine reserve of Italy. Conserv. Biol. 16, 515–526. http://dx.doi.org/10.1046/j.1523-1739.2002.00425.x.

Vucetich, J.A., Bruskotter, J.T., Nelson, M.P., 2015. Evaluating whether nature's intrinsic value is an axiom of or anathema to conservation. Conserv. Biol. 29, 321–332. http://dx.doi.org/10.1111/cobi.12464.

Ward, J.V., Tockner, K., Schiemer, F., 1999. Biodiversity of floodplain river ecosystems: ecotones and connectivity1. Regul. Rivers Res. Manage. 15, 125–139. http://dx.doi.org/10.1002/(SICI)1099-1646(199901/06)15:1/3<125::AID-RRR523>3.0.CO;2-E.

Weslawski, J., Warzocha, J., Wiktor, J., Urbanski, J., Bradtke, K., Kryla, L., Tatarek, A., Kotwicki, L., Piwowarczyk, J., 2009. Biological volarisation of the Southern Baltic Sea (Polish Exclusive Economic Zone. Oceanologia 51, 415–435.

Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J., Watson, R., 2006. Impacts of biodiversity loss on ocean ecosystem services. Science (80-.) 314 787 LP – 790.

WoRMS Editorial Board (2017). World Register of Marine Species. Available from http://www.marinespecies.org at VLIZ. Accessed 2017-02-01. doi: 10.14284/170.