

Areas of ecological relevance in the Balearic Sea:

Identification and
methodological proposal



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INDEX

Abstract	04
1. Introduction	05
2. Material and methods	07
2.1. Study area	09
2.2. Compilation of spatial layers and metadata catalogue	10
2.3. Data processing and indicator development	10
2.3.1. Criterion 1: Biodiversity	12
2.3.2. Criterion 2: Fishery resources	16
2.4. Generation of final maps	16
2.5. Expert guide	16
3. Results	17
3.1. Sub-criteria indices	17
3.2. Biodiversity and fishery resources indices	19
3.3. Ecological Relevance Index	19
4. Conclusions	21
5. Limitations and recommendations	21
6. References	22
7. Annex I	26
7.1. Figures	26
7.2. Tables	39

ABSTRACT

In the context of constantly increasing environmental and anthropogenic pressures, the conservation of the oceans has become a global priority. The Balearic Islands are a clear example. Preserving their biodiversity and fishery resources in the face of the impacts derived from these pressures is essential for the economic and social sustainability of the region.

This study evaluates the ecological relevance of the Balearic Sea based on spatial indicators, combining scientific information and local expert knowledge. The heterogeneity of the region's ecosystems is reflected in the spatial distribution of the indices developed, whose highest values are concentrated in areas close to the coast and at some points in open waters, such as seamounts. The areas of high and very high ecological relevance we identify in this study occupy 13% of the total Balearic Sea area, and are mainly concentrated in open waters (11.6%).

When analysing the values for each area, these areas account for 15% of the coastal waters and the continental shelf with respect to their total surface area, and places such as the Cap de Formentor, and the Menorca Channel stand out. In open waters, they account for 12.7%, and are mainly located on seamounts, including Ausiàs March, Ses Olives, Émile Baudot, and Mount SSS. These are not, however, the only relevant areas of the Balearic Sea, rather the only ones that can be objectively and quantitatively identified with the information currently available. In this way, the recognition of these areas becomes a fundamental step to implement strategies aligned with the 10x30 conservation objectives, promoting the resilience of the ecosystems of the Balearic Sea.

Keywords: Balearic Islands, ecological relevance, ocean conservation, environmental and anthropogenic pressures

1. Introduction

Oceans have historically been fundamental pillars of human development, providing resources, sustaining cultures and generating economic wealth (Bennett, 2019; Costanza, 1999). However, steady population growth and the expansion of human activities have intensified the pressures and impacts affecting the marine environment to the point of compromising its status and sustainability (Halpern et al., 2019; Jouffray et al., 2020; Pörtner et al., 2023). From local pressures such as direct habitat degradation, declining fish stocks, and pollution, to global pressures such as climate change, the impacts generated not only threaten their biodiversity, but also the essential ecosystem services they provide (e.g. climate regulation, food provision, coastal defence (Balvanera et al., 2017; Cooley et al., 2023; Culhane et al., 2018; Halpern et al., 2019).

Against this backdrop, ocean conservation has become a global priority (Borja et al., 2020; Claudet et al., 2020; Rees et al., 2018; Saeedi et al., 2019; Sala et al., 2021; Vaughan et al., 2019; Visbeck et al., 2014). Bodies such as the Convention on Biological Diversity (CBD), the International Union for Conservation of Nature (IUCN), and the United Nations (UN; sustainable development goal 14) have pushed for a target of **protecting at least 30 % of the oceans by 2030**, with a **minimum of 10 % under strict protection** measures (30x30 and 10x30 targets). However, progress towards these targets is uneven across countries and regions (Aminian-Biquet et al., 2024; Pike et al., 2024), and the designation of areas for strict protection remains limited due to the socio-economic and political trade-offs involved (Grorud-Colvert et al., 2021; Stevenson et al., 2020).

In response, marine protected areas (MPAs) have emerged as a **key tool** for the protection and restoration of marine biodiversity (Sala & Giakoumi, 2018). They have demonstrated that they can mitigate anthropogenic impacts and strengthen ecosystem resilience to climate change (Giakoumi et al., 2017; Jacquemont et al., 2022; Roberts et al., 2017; Sala et al., 2018). Furthermore, protecting ecosystem services also contributes to the wellbeing of the local communities that depend on them (Ban et al., 2019; Grorud-Colvert et al., 2021; Mascia & Claus, 2009; Nowakowski et al., 2023).

However, many MPAs in the Mediterranean have minimal protection and poor management, which limits their effectiveness (Aminian-Biquet et al., 2024; Claudet et al., 2020). Among other factors, the effectiveness of MPAs depends on size, location, level of restriction, and ecological connectivity (Claudet et al., 2008; Gaines et al., 2010; Grorud-Colvert et al., 2014; Roberts, 2000; Sala et al., 2002, 2021). In particular, so-called **strict protection areas**, where human activities are fully or highly restricted, have been shown to be the most effective in terms of biomass recovery and ecosystem structure, thus fostering ecosystem complexity and resilience (Grorud-Colvert et al., 2021; Lester et al., 2009; Sala & Giakoumi, 2018; Sala et al., 2018; Zupan et al., 2018).

One of the main obstacles in the implementation of these areas is the lack of standardised criteria and clear methodologies for their delimitation, which hinders informed decision-making (Grorud-Colvert et al., 2021; Rilov et al., 2020). This is compounded by the scarcity of spatial data in many regions, forcing the basing of marine spatial planning on fragmented or poorly quantifiable information (Costello et al., 2010; Guerrero et al., 2013; Rowell et al., 2022). It is therefore crucial to **develop tools** that integrate the ecological and socio-economic complexity of marine systems in an objective manner applicable to different conservation scenarios (van Denderen et al., 2024; Rowell et al., 2022; Visalli et al., 2020).

The **Balearic Sea** is representative of this problem. It is an enclave with a high diversity of habitats (Báez et al., 2019; Farriols et al., 2019; Julià et al., 2019) exposed to multiple climatic and anthropogenic impacts (Barrientos et al., 2024; Ramírez et al., 2018). Despite scientific and management advances in the region, the MPA is still insufficient: only 13.8% of its waters have some form of protection, and only 0.07% have strict protection (Marilles Foundation, 2024). Moreover, most conservation efforts have focused on the coastal strip, leaving deeper and/

or open water areas in the background (Ballesteros, 2022). In this context, the Balearic Islands have the opportunity – and the need – to move towards the 10x30 conservation target.

To date, the most comprehensive initiative to define strictly protected marine areas in the Balearic Sea comes from **Enric Ballesteros** (2022), who, as a biodiversity expert in the region, proposed priority areas for conservation based on the presence of vulnerable, rare, and unique species and habitats. However, his approach, based mainly on qualitative literature without detailed spatial data, entails a certain degree of subjectivity in the prioritisation of areas, which makes it difficult to apply directly to conservation strategies based on spatial planning.

This study seeks to complement the work of Ballesteros (2022) by developing a methodology based on quantitative scientific data of high spatial resolution, which allows more objective identification with greater spatial precision of the areas of greatest ecological relevance for the conservation of biodiversity and the sustainability of fishery resources in the Balearic Sea. This in turn facilitates decision-making in the designation of potential areas of strict protection. In addition, it incorporates the knowledge of experts in the region to improve planning in areas where information is more limited. Therefore, the study not only offers a concrete proposal for the Balearic Sea, but also proposes a methodology that can be replicated in other regions with similar characteristics and/or information.



2. Material and methods

We defined ecological relevance in the Balearic Sea semi-quantitatively according to two main criteria – biodiversity and fishery resources – each with sub-criteria reflecting different ecological aspects (Box 1).

CRITERIA AND SUB-CRITERIA ESTABLISHED FOR ASSESSING THE ECOLOGICAL RELEVANCE OF THE BALEARIC SEA:

■ **Criterion 1. Biodiversity.** Defines the natural values of the region. It is composed of the following sub-criteria:

—○ Sub-criterion 1. **Presence of protected, vulnerable and unique habitats.** This includes the composition, structure and vulnerability of these habitats.

—○ Sub-criterion 2. **Presence of protected, vulnerable and unique species.** Provides information on the richness and current and potential distribution of these species.

—○ Sub-criterion 3. **Presence of seamounts or similar geomorphological elevations.** Identifies essential habitats or other key areas for the persistence of biodiversity.

—○ Sub-criterion 4. **Important areas for biodiversity.** Identifies essential habitats or other key areas for the persistence of biodiversity.

—○ Sub-criterion 5. **Ecological vulnerability of the coast.** Shows the susceptibility of the coastline according to its geomorphological characteristics and the costs associated with pollution.

—○ Sub-criterion 6. **Figures of protection.** Reflects those areas that have already been designated or proposed for protection under different legislative frameworks as their ecological relevance is fully or partially known.

■ **Criterion 2. Fishery resources.** Considers habitats essential for the recovery of exploited marine resources, focusing on two sub-criteria:

—○ Sub-criterion 1. **Spawning areas or species of commercial interest.** Delimits the areas where these species aggregate on a recurrent basis to reproduce.

—○ Sub-criterion 2. **Breeding areas for species of commercial interest.** Identifies areas where juveniles are concentrated in their first and second year, considering their persistence in time and space.

Based on these sub-criteria and using the scientific information available to date, we calculated different indicators to assess spatial ecological relevance. We used a similar approach to that described in the rapid assessment by Alvarez-Berastegui et al. (2014), designed to quickly and efficiently assess the environmental and ecological characteristics of coastal areas without the need for extensive in situ sampling.

To improve the accuracy of the spatial assessment and to make up for the lack of information in some areas, we combined the results of the indicators with the knowledge of a committee of experts from the region (Figure 1).

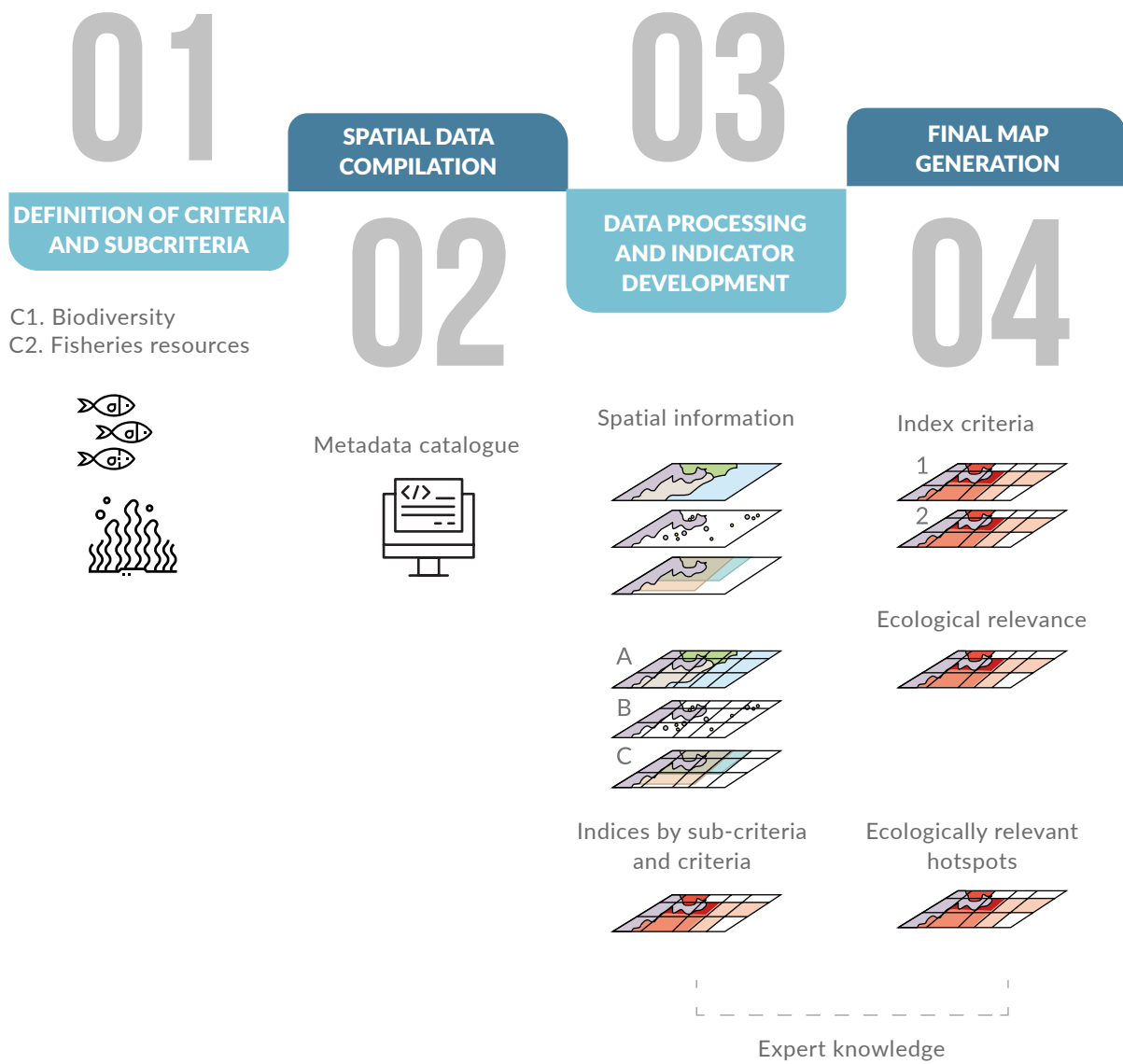


Figure 1. Methodology used throughout the study.

2.1. Study area

To accurately assess the ecological relevance of marine ecosystems in space and to calculate the percentage of surface area they occupy, it is essential to establish the **geographical limits of the Balearic Sea**, for the delimitation of which there is no clear consensus. Recently, Ballesteros (2022) proposed two delimitations: one under biological criteria, delimited by the 2,600 m depth isobath; and another under geological criteria, where the abyssal plane covers a larger area and includes an additional seamount.

For this study, we adopted the biological delimitation (Ballesteros, 2022), which defines the Balearic Sea as a region that includes the Balearic promontory (Acosta et al., 2003), covering the seabed above 2,600 m depth. Its limits are established by the maximum depth of the Ibiza Channel to the west, the Valencia Channel to the north, the beginning of the abyssal plane of the Provençal-Balearic Basin to the east, and the Algero-Balearic Basin to the south (Acosta et al., 2004; Díaz & Maldonado, 1985). It comprises a total area of 72,555 km² (Figure 2).

The diversity of marine ecosystems in the Balearic Sea, as well as the typology and intensity of stressors and impacts and the availability and resolution of spatial information, is highly variable. To obtain a more complete vision, adjusted to the availability of data and its characteristics, we structured this study in two different areas within the limits of the Balearic Sea (Figure 2):

■ **Coastal waters and surface shelf.** Covers from the coastline to 100 m depth.

■ **Open water.** Covers from the 100 m isobath to the limit of the Balearic Sea as defined above.

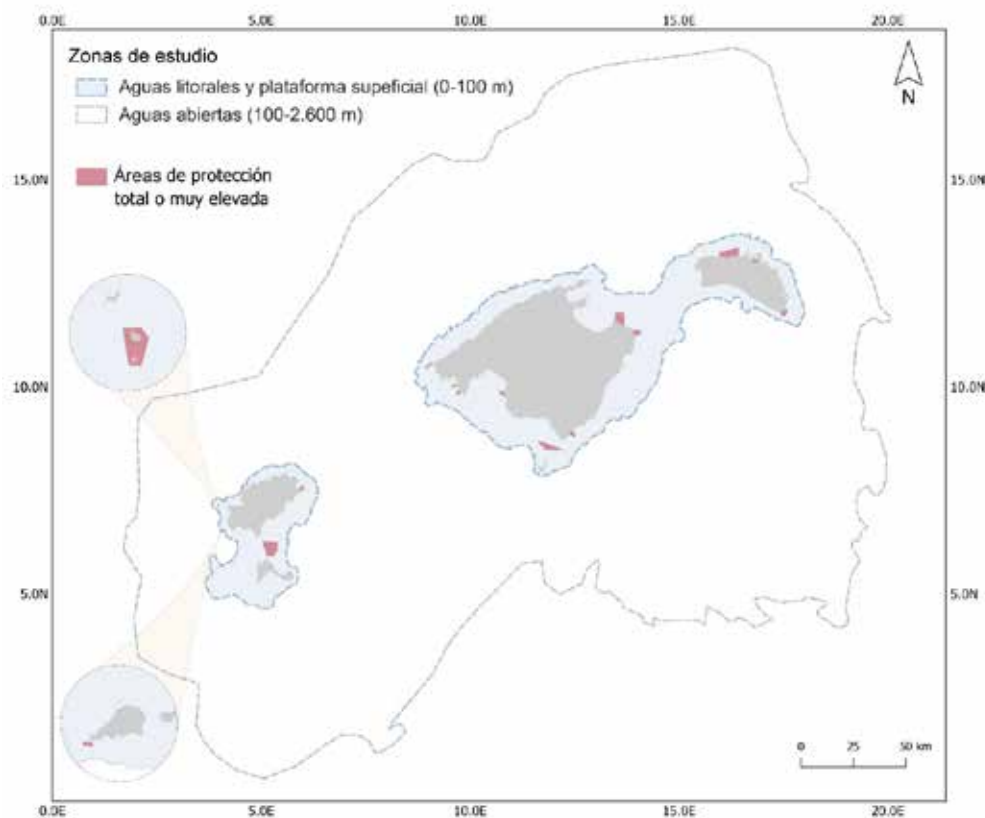


Figure 2. Delimitation of the Balearic Sea according to Ballesteros (2022) and the two differentiated study zones: (i) coastal waters and surface shelf, and (ii) open waters. The current total protection zones (0.07% of the Balearic Sea) include the areas of special protection, maximum protection, restricted use, and integral reserves; the high protection zones include the special diving and recreational fishing closed areas (Marilles Foundation, 2024).

2.2. Compilation of spatial layers and metadata catalogue

For the development of this study, we collected different open access spatial databases and information obtained in campaigns and research projects. Initially, we carried out an exhaustive search of databases at regional (e.g. [Portal Dades Obertes GOIB](#)), national (e.g. [Spatial Data Infrastructure](#) of the Ministry for Ecological Transition and the Demographic Challenge-IDE), European (e.g. [European Marine Observation and Data Network-EMODnet](#)), and international (e.g. [Ocean Biodiversity Observation System-OBIS](#)) levels. We also reviewed websites and scientific-technical reports from different scientific institutions, such as the Spanish Institute of Oceanography (IEO) and the Coastal Observation System of the Balearic Islands (SOCIB); foundations dedicated to the conservation of the marine environment (e.g. OCEANA); and peer-reviewed scientific literature that could contain useful information for the ecological and management characterisation of the Balearic Sea.

In this first phase of the study, we included all the spatial information (i.e. layers) collected in a metadata catalogue (Annex 1, Figure A1), specifying and summarising different characteristics that allowed us to evaluate its usefulness. We compiled these characteristics in **four main blocks** for this study: descriptive information, technical information, accessibility, and suitability (Annex 2).³ In total, we compiled **324 spatial information layers**, classified into four main categories: (1) Habitat, (2) Human pressures, (3) Management, and (4) Environmental variables. For the spatial analysis of the Balearic Sea, we selected only those layers related to its ecological relevance (Annex 1, Table A1). We processed and georeferenced these layers in a Geographic Information System using QGIS 3.34.11 (QGIS.org, 2024), using the UTM ETRS 89 ZONE 31 N projection system.

2.3. Data processing and indicator development

We processed the selected layers (Annex 1, Table A1) to develop different individual indicators (Figure 1; Table 1) describing the previously defined criteria (Box 1). For example, we transformed the spatial information collected in the bionomic mapping of the Balearic Sea into the number of habitats indicator. Thus, we divided the study area into grids assigning each grid the corresponding value for each individual indicator. To facilitate interpretation and comparison between indicators (Hargrave, 2002), we standardised their values to a semi-qualitative scale of five categories: (1) Very low, (2) Low, (3) Moderate, (4) High, and (5) Very high (Annex 1, Table A2). Where a cell contained multiple standardised values for the same indicator (due to the nature of the original data layer), we designated the highest value observed in that cell (Hargrave, 2002).

We subsequently aggregated the individual indicators into indices describing the corresponding sub-criteria (Figure 1) to facilitate their treatment and interpretation (Ebert & Welsch, 2004; Hargrave, 2002). Thus, for example, the individual indicators of main habitat, number of habitats, and habitat were grouped into a single Habitat index (Table 1; Annex 3), defined by the mean value of these indicators. We then aggregated the sub-criteria indices according to the main criteria, resulting in two final indices for biodiversity and fisheries resources. Finally, both were combined to obtain a single **Balearic Sea Ecological Relevance Index** (Figure 1).

We carried out all integration and processing of spatial layers, grid generation, and indicator development in QGIS 3.34.11 (QGIS.org, 2024) and R 4.4.1 (R Core Team, 2024). Given the differences in data availability and resolution in the two defined zones within the Balearic Sea (Figure 1), we generated grids of different sizes: (1) a 1x1 km grid for the littoral waters and shallow shelf zone (0–100 m), adjusted to a higher resolution to allow for more detailed spatial planning; and (2) a 2x2 km grid in the open water zone (100–2,600 m), according to the lower availability and resolution of data in deeper waters.

Tabla 1. List of indicators and indices developed to define the ecological relevance of the Balearic Sea according to the established biodiversity and fishery resource criteria.

Criterion/Index	Sub-criterion/Index	Indicator	Variable
Biodiversity	Habitats	Main habitat	Habitat with the highest coverage
		Number of habitats	Number of different habitats
		Protected habitat	Number of conventions, directives, and other legislative frameworks in which the habitat is included
	Species	Number of protected species (10 years)	Occurrence of protected species (in the last 10 years)
		Potential habitat for protected species	Occurrence of protected species (historically)
		Species richness	Species occurrence
	Seamounts	Seamounts ¹	Presence of seamounts or similar geomorphological elevations
	Important areas for biodiversity	Important areas for biodiversity	Number of areas important for biodiversity
	Ecological vulnerability	Ecological vulnerability ²	Vulnerability based on shoreline typology, wave exposure, protection status, and pollution costs
	Figures of protection	Number of protection figure	Number of protection statuses designated to protect specific habitats and species
Number of proposals		Number of protection figures proposed by other researchers/organisations	
Ballesteros protection levels (2022)		Weighted protection level of the Ballesteros (2022) proposal, where he designates these areas in terms of unique, rare, vulnerable species/habitats	
Fisheries resources	Spawning areas	Number of spawning areas	Number of species using this area for spawning
		Level of persistence of spawning areas	Average level of persistence of the species using the area for spawning
	Breeding areas	Number of breeding areas	Number of species using the area for breeding
		Level of persistence of breeding areas	Average level of persistence of the species using the area for breeding

(1,) (2) Indicators used only in open water, and in littoral and shallow shelf waters, respectively.

2.3.1. Criterion 1: Biodiversity

The *biodiversity* criterion defines the natural values of the Balearic Sea. We developed 20 individual indicators in this category, finally selecting 12 that we subsequently grouped into 6 indices or sub-criteria (Table 1).

The **Habitat index** (sub-criterion 1) is composed of the individual indicators Main habitat Number of habitats, and Protected habitat [(Table 1; Annex1 (A1))].⁴ For its development, we compiled and unified existing bionomic maps, prioritising the most updated and complete layers in case of overlapping (A1, Table A1). As the unified layers had different habitat classification systems and different spatial resolutions, we standardised the final layer by grouping habitats into **8 main categories**: Grassland, Caulerpa, Precoralligenous, Coralligenous, Maërl, Detritic, Laminaria, Rocky, and Sedimentary (Figure 3; A1, Table A3).

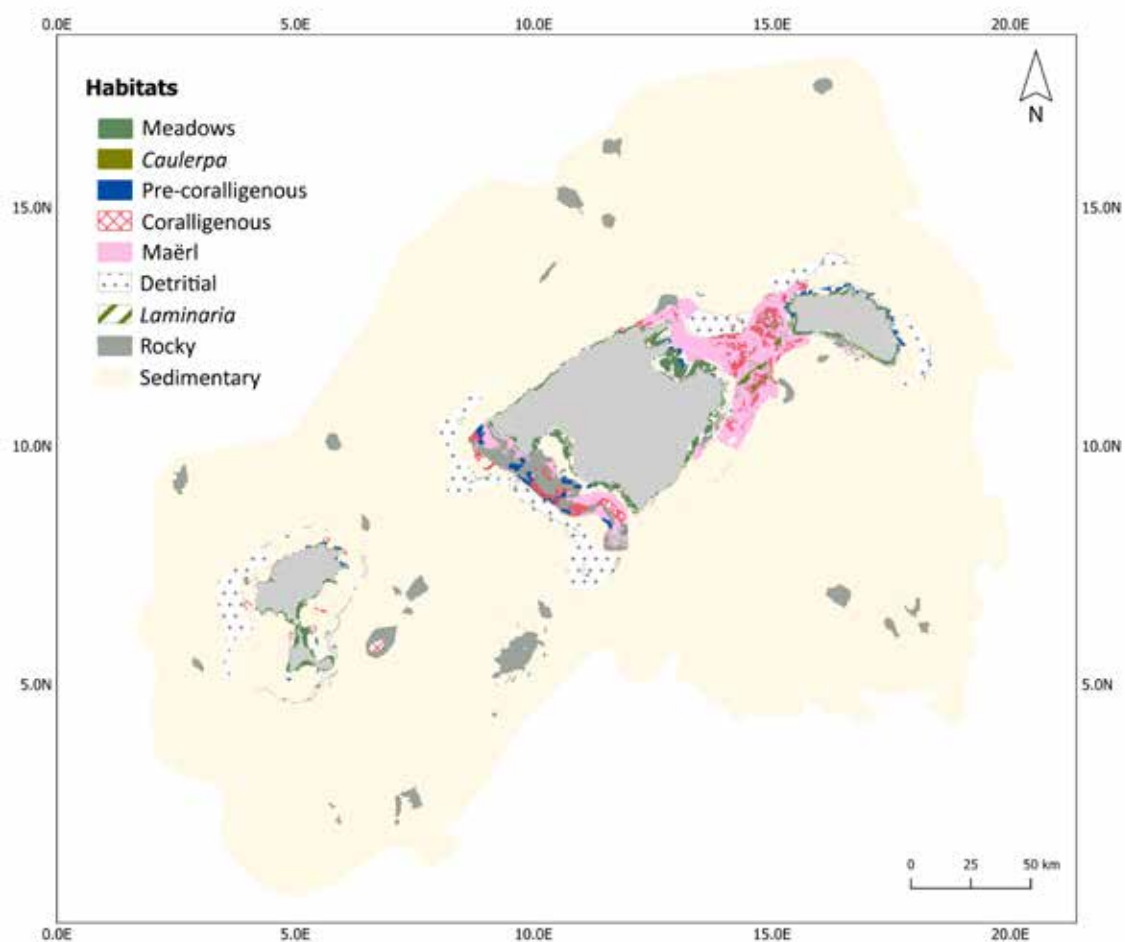


Figure 3. Bionomic mapping of the Balearic Sea processed and standardised to develop habitat indicators.

The **Species Richness index** (sub-criterion 2) is based on the indicators Number of protected species (10 years), Potential habitat of protected species, and Species richness (Table 1; Annex 3). We based the species richness indicator on the [Atlas of the Balearic Sea](#), which includes records of **1,535 species in the study area** from 1970 to 2010 (Deudero et al., 2011; Annex 2, Table A1). In addition, we identified 198 protected species listed in different red lists and conventions in the study area. However, to calculate the first two indicators, we selected a representative sample of only 20 of these species (Table 2) based on the following criteria:

■ **Level of protection.** We prioritised species categorised by the Red List of Threatened Species of the Balearic Islands as vulnerable, endangered, or critically endangered, as well as those included in different European and regional conventions and directives (Table 2). Within these, we prioritised species included in the Habitats Directive, the Nature Restoration Regulation, and the Barcelona Convention at European level.

■ **Taxonomic diversity.** We selected species from different taxonomic groups to obtain a broader and more representative view of the protected biodiversity of the study area.

■ **Ecology and distribution.** In addition, we prioritised the selection of species with a key role for the ecosystem (e.g. structuring species), as well as those with distributions with less uncertainty (e.g. benthic species), avoiding highly mobile species to obtain a more realistic and predictable scenario of their presence in a given area.

■ **Data availability and reliability.** Finally, we restricted the selection to the availability of occurrence data recorded in the [Ocean Biodiversity Information System](#) (OBIS) and [Global Biodiversity Information Facility](#) (GBIF) reference databases, discarding those with insufficient or unreliable information.



Table 2. List of selected protected species, indicating the reference documents in which their protection status is stated.

Group	Species	IUCN Balearic Islands	LESRPE	Habitats Directive	Nature Restoration Regulation	Barcelona Convention	Berne Convention	IUCN Mediterranean
Chlorophyta	<i>Caulerpa prolifera</i>		Special protection		Annex II			
Cnidaria	<i>Corallium rubrum</i>	Endangered		Annex V	Annex II	Anexo III	Annex III	Endangered
	<i>Cladocora caespitosa</i>	Endangered	Special protection	Annex I	Annex II	Annex II		Endangered
	<i>Dendrophyllia cornigera</i>	Endangered		Annex I		Annex II		Endangered
	<i>Isidella elongata</i>	Critically endangered		Annex I		Annex II		Critically endangered
	<i>Paramuricea clavata</i>	Vulnerable		Annex I	Annex II			Vulnerable
Crustacea	<i>Scyllarides latus</i>	Endangered		Annex V		Annex III	Annex III	
Echinodermata	<i>Centrotephanus longispinus</i>	Minor concern	Special protection	Annex IV		Annex II	Annex II	
Heterokontophyta	<i>Laminaria rodriguezii</i>		Special protection	Annex I	Annex II	Annex II	Annex I	
	<i>Ericaria amentacea</i>		Special protection	Annex I	Annex II	Annex II	Annex I	
	<i>Ericaria crinita</i>		Special protection	Annex I	Annex II	Annex II		
	<i>Gongolaria barbata</i>		Special protection	Annex I	Annex II	Annex II		
	<i>Ericaria brachycarpa</i>		Special protection	Annex I		Annex II		
Magnoliophyta	<i>Posidonia oceanica</i>	Vulnerable*	Special protection	Annex I	Annex II	Annex II	Annex I	Minor concern
	<i>Cymodocea nodosa</i>		Special protection	Annex I	Annex II	Annex II	Annex I	Minor concern
	<i>Zostera noltei</i>		Special protection	Annex I	Annex II	Annex II		Minor concern
Mollusca	<i>Dendropoma cristatum</i>	Vulnerable	Vulnerable	Annex I		Annex II	Annex II	
	<i>Charonia lampas</i>	Vulnerable	Vulnerable			Annex II	Annex II	
	<i>Pinna rudis</i>	Vulnerable	Special protection			Annex II	Annex II	
Porifera	<i>Thenea muricata</i>	Vulnerable			Annex II			

*Decree 25/2018, of 27 July, on the conservation of *Posidonia oceanica* in the Balearic Islands.

The **Seamounts indicator** (sub-criterion 3) shows the area occupied by seamounts or similarly structured geomorphological elevations (Table 1; Annex 3). The available information in most cases only indicates their location, but not their extent. Therefore, we delimited their extent on the basis of two high-resolution Digital Terrain Models (DTMs) (Annex 2, Table A1): one derived from the bathymetry of the [Spatial Data Infrastructure of the Balearic Islands \(IdeIB\)](#) and another open access model from the [European Marine Observation and Data Network \(EMODnet\) Bathymetry \(DTM, 2022\)](#)

For the **Important Biodiversity Areas indicator** (sub-criterion 4), we combined four distinct areas (Table 1; Annex 1, Table A1) representing essential habitats for biodiversity or specific taxonomic groups (e.g. elasmobranchs, marine mammals) (BirdLife International, 2024; CBD, 2015; IUCN-MMPATF, 2017; IUCN SSC Shark Specialist Group, 2022), designed to support management tools such as MPAs.

The **Ecological Vulnerability indicator** (sub-criterion 5) is based on a single indicator developed in the State Plan for the Protection of the Sea Shore against Pollution (Plan RIBERA, 2014), to analyse the environmental risks of shoreline pollution from possible oil spills (Table 1; Annex 1, Table A1). This vulnerability is defined on the basis of the geomorphological characteristics of the coast, its degree of exposure to waves, its inclusion within a protected area, and the clean-up costs in the event of pollution. .

The **Protection Figures index** (sub-criterion 6) includes various indicators, both of figures already established and those proposed by other researchers or organisations within the same legislative frameworks (Table 1). Specifically, we considered the following (see Annex 1, Table A1 for the complete list of figures): :

■ **Number of protection figures.** It includes all the local and national figures legally designated in the Balearic Sea to protect specific habitats and species, regardless of the level of protection.

■ **Number of proposals.** Areas suggested by researchers and foundations for the conservation of the marine environment for protection within the same legal frameworks and reflecting the ecological relevance of the area. We included 8 Sites of Community Importance (SCIs), 2 Fisheries Restricted Areas (FRAs), 3 MPAs, and 10 marine refuges.

■ **Ballesteros protection levels (2022).** We weighted the 4 protection categories proposed in this work according to the level of restriction from lowest to highest, including 5 proposed Special Conservation Areas (SCAs), 27 Marine Protected Areas or Fisheries Interest Reserves (MPAs), 24 No Fishing Areas (NFAs), and 11 Total or Integral Reserves (RIs).

2.3.2. Criterion 2: Fishery resources

The Fishery Resource criterion focuses on the concept of *Essential Fish Habitats*, understood as 'habitats identified as essential for the ecological and biological requirements of the critical life history stages of exploited fish species' (Scientific, Technical and Economic Committee for Fisheries, 2006). For their assessment, we created 4 individual indicators grouped into 2 indices or sub-criteria.

For the **Spawning Grounds index** (sub-criterion 1), we developed 2 indicators, Number of spawning grounds and the Level of persistence of spawning grounds (Table 1; Annex 2, Table A1) for 4 of the most commercially important species in the western Mediterranean: red mullet (*Mullus surmuletus*), mud mullet (*M. barbatus*), European hake (*Merluccius merluccius*), and short-finned squid (*Illex coindetii*).

We created the **Nursery Area index** (sub-criterion 2) using the indicators Number of nursery areas and Level of nursery area persistence (Table 1; Annex 1, Table A1) for European hake (*M. merluccius*) and blackmouth catshark (*Galeus melastomus*).

The 4 indicators are based on the Essential Fish Habitats of the Balearic Sea identified in the MediSeH project. The level of persistence of each indicator reflects the frequency with which an area has been identified as a nursery or spawning ground over the 4 years of the project study (2007-2010), indicating its recurrent importance.

2.4. Generation of final maps

The final map for each criterion (biodiversity and fishery resources) resulted from the average value of the indices of the corresponding sub-criteria. In turn, the combination of the maps for each criterion defines the values of the ecological relevance of the Balearic Sea, calculated for each grid cell (Figure 1). To contextualise the robustness of the results, we developed a Confidence Indicator to reflect both the availability of data in each area and the number of indicators used in the calculation of the final index.

2.5. Expert guide

We completed the evaluation of the indicators and indices with the **advice of a committee of experts** from the region to address information limitations in some areas and the relevance and certainty of the information collected (Figure 1). Ten experts in different fields actively advised throughout the study process, including experts in Balearic biodiversity, fisheries resources, artisanal fisheries, coastal communities, benthic habitats, pelagic systems, elasmobranchs, MPAs, and climate change.

The committee assessed the relevance of individual indicators for their appropriateness in the creation of indices and final products. In this consultation, the experts assigned a score from 1 to 5 according to the level of importance to each indicator, considering the objectives of this study as well as the ability of the indicators to capture and represent spatial patterns adequately with respect to their knowledge of the study area. Finally, they also self-assessed the confidence level of their answers on a scale of 1 to 3. Higher values indicated higher importance and confidence in the assessment, results we considered when selecting the final indicators for each sub-criterion.

3. Results

3.1. Sub-criteria indices

The indicators and indices of biodiversity and fishery resources generated for the Balearic Sea show a heterogeneous spatial distribution, with different patterns depending on the sub-criterion evaluated (Figure 4; Annex 3). In general, the highest values are mostly concentrated on the islands of Mallorca and Menorca, where coastal areas are particularly noteworthy. In contrast, open waters show generally low values for all indices, with the exception of seamounts..

The **Habitat index** (Figure 4a) reaches its highest values in the areas closest to the coastline, as well as in the Menorca Channel and the south of Palma Bay between 40 and 100 m depth. Unlike the latter, the distribution of the Species Index is more fragmented, showing high and very high values in the north and northwest of Mallorca, both in coastal and open waters, and on the north and east coast of Menorca, mainly in the areas closest to the coastline. There are also some isolated areas to the south of Formentera with high values of species diversity.

The **Important Biodiversity Areas** (Figure 4b) are concentrated in Menorca – especially in the north, east, and southeast of the island – and in the southeast of the island of Cabrera. Some areas on Formentera, the south coast of Menorca and Mallorca also stand out. On the other hand, the Ecological Vulnerability (Figure 4), assessed only at 0 m depth, follows a completely different spatial pattern. Menorca has high values along almost all of its coasts, while in Mallorca the bays of Pollença (mainly) and Alcúdia have the highest ecological vulnerability in the study area.

The distribution of the **Figures of Protection** (Figure 4c) in the Balearic Sea reinforces the patterns described herein. Most are located in coastal areas, such as the Formentor peninsula, the north of Menorca, Es Freus in Ibiza, and Formentera. However, high and very high values are also found in open waters, such as in some seamounts – Ausiàs March, Ses Olives, Émile Baudot, and Stone Sponge Seamount (Mount SSS) – and in the Menorca Channel.

In terms of fishery resources, the **Breeding Area and Spawning Area indices** (Figure 4d and 4e) show a relatively homogeneous distribution along the end of the continental shelf and the edge of the slope, with higher values of the Breeding Area index around Menorca and Mallorca at depths greater than 100m. In contrast, spawning areas are mainly concentrated on the shelf along the northern part of the Serra de Tramuntana and Formentor peninsula, as well as in some areas of the Menorca Channel and south of the Bay of Palma.

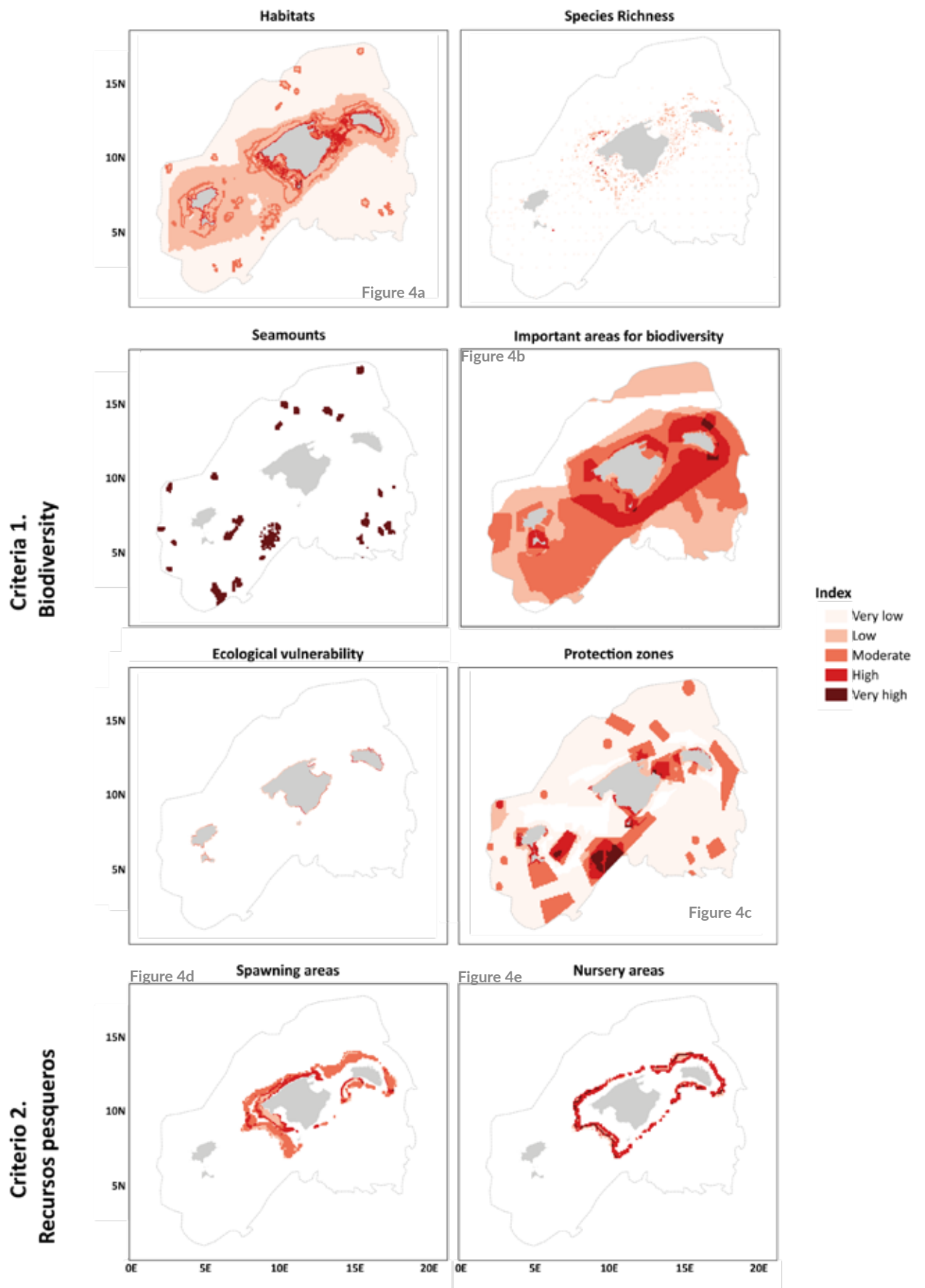


Figure 4. Spatial distribution of the indices corresponding to each sub-criterion..

3.2. Biodiversity and fishery resources indices

The Biodiversity and Fishery Resource indices present contrasting spatial patterns (Figure 5; Annex 3). While the Biodiversity index covers the whole Balearic Sea with a heterogeneous and patchy spatial pattern, the Fishery Resources index is mainly restricted to the Balearic promontory around Menorca and Mallorca.

The **areas with high and very high biodiversity** (Figure 5) are concentrated in coastal areas, including the islands of Cabrera, Sa Dragonera, and El Toro, as well as the peninsula of Formentor, the north of Menorca, Es Freus, and the islets of Ponent. In open waters, the seamounts stand out as the most biodiverse spots. In general, biodiversity decreases as one moves away from the coast, especially in the sedimentary bottoms of open waters. In contrast, the areas of greatest biodiversity are associated with habitats such as coraligenous, detrital seabeds, and seagrass beds.

As of the **Fishery Resources index** (Figure 5), although it generally shows high values, the areas of greatest concentration do not always coincide with those of greatest biodiversity. Although some areas overlap – such as the Formentor peninsula, the island of Dragonera, and the edge of the continental shelf in Menorca – the most outstanding areas for fishery resources are found on the coast of the Serra de Tramuntana and to the south of the Bay of Palma, where, on the contrary, the biodiversity index shows lower values.

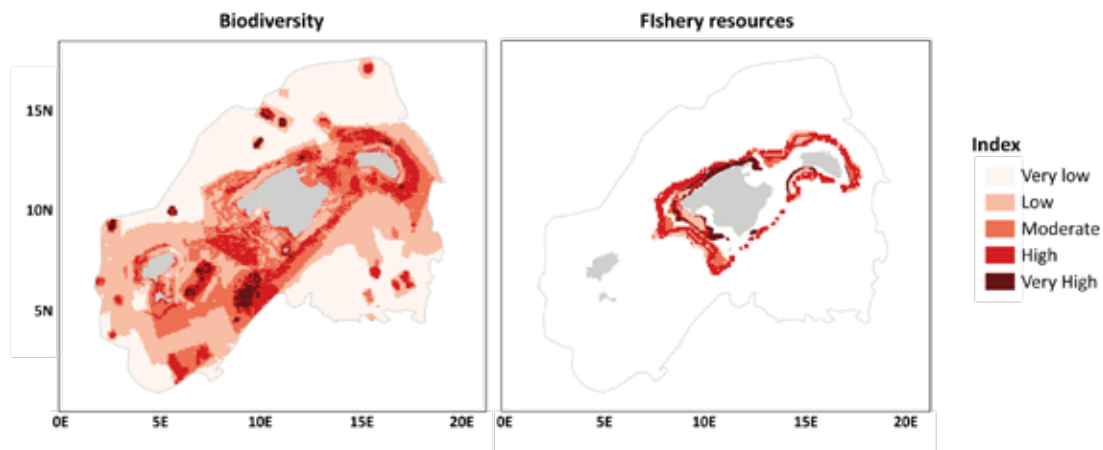


Figure 5. Spatial distribution of biodiversity indices and fishery resources.

3.3. Ecological Relevance Index

The Ecological Relevance index within the Balearic Sea identifies 13 % of its marine area with high (11.3 %) or very high (1.7 %) values (Figure 6; Annex 3). Most of these areas are in open waters and account for 11.6 % of the region's total, while in coastal waters and on the surface shelf this percentage is 9 times lower (1.4 %).

When the areas of high and very high ecological relevance are studied with respect to the total area of each zone, in coastal waters and on the surface shelf they occupy 15 % of their surface area. However, in open waters this value is reduced (12.7%). In both, the areas of very high ecological relevance represent a low percentage, only 0.3 % in coastal waters and on the surface shelf and 1.7 % in open waters (Figure 6).

Coinciding with the distribution observed for Biodiversity and fishery resources (Figure 5), areas of high and very high ecological relevance in the coastal zone and on the shelf include the Formentor peninsula, the island of Sa Dragonera, the south coast of Mallorca, the island of Cabrera, the Menorca Channel, and the north of Menorca; and Es Freus and the islets of Ponent and Tagomago in Ibiza and Formentera (Figure 6).

In open waters, very high ecological relevance values are concentrated almost exclusively in the seamounts, among which Ausiàs March, Ses Olives, Émile Baudot, and Mount SSS stand out, as well as in some areas close to the island of Cabrera, the east of Menorca, and the islet of Es Vedrà (Ibiza). Also noteworthy are some areas of high ecological relevance located on the edge of the continental shelf in Mallorca and Menorca, such as the Formentor peninsula and the Menorca Channel, as well as the rest of the seamounts (Figure 6).

Some **19.8%** of the Balearic Sea is characterised by **moderate ecological relevance**, usually around areas of high or very high ecological relevance, such as most of the seamounts or the edge of the continental shelf and slope, the Menorca Channel or, in general, the areas closest to the coastline of the whole archipelago (Figure 6).

In contrast, areas of **low or very low ecological relevance** coincide mainly with sedimentary habitats, extending over much of the open water and, more occasionally, in littoral waters and on the surface shelf (Figure 6).

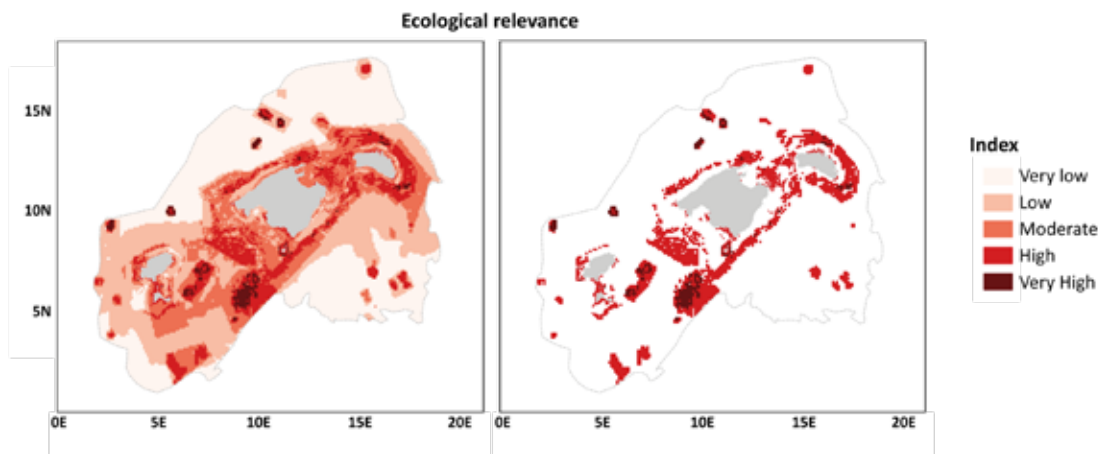


Figure 6. Spatial distribution of the ecological relevance index of the Balearic Sea (left) and of the areas of high and very high ecological relevance (right).

The number of indicators used to calculate the ecological relevance index also varies spatially due to the limitations of available information (Figure 7). Thus, the edge of the continental shelf and the upper slope are the areas with the most complete information. Particularly, the areas of Mallorca and Menorca, at depths between 0 and 100 m, are those with the greatest availability of spatial data. The lack of quantitative spatial information is mainly reflected in open waters, where in some points only three indicators could be calculated. In coastal waters and on the surface shelf, information gaps are observed, mainly on the islands of Ibiza and Formentera.

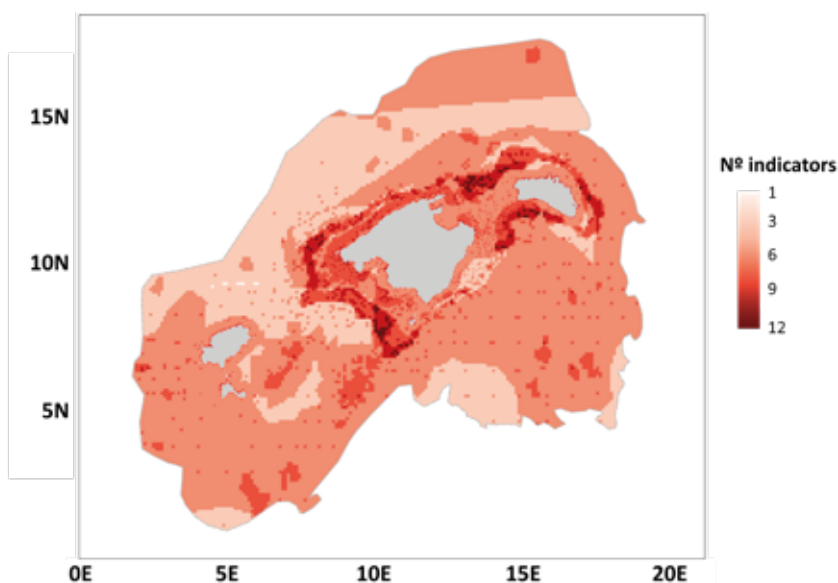


Figure 7. Number of indicators used for the development of the ecological relevance index. The number of indicators used is limited by the amount of quantitative spatial information available.



4. Conclusions

In this study, we carried out the first detailed assessment of the ecological relevance of the Balearic Sea using the best available spatial information. The methodology we used has proved to be an effective tool to identify these areas in a systematic and reproducible way by means of easily comparable and interpretable indicators. Furthermore, combining the available spatial information with expert knowledge has allowed us to adjust the distribution of ecologically relevant areas, which facilitates their application in marine conservation planning (Figure 1).

The distribution of biodiversity indices and fishery resources shows a clear heterogeneity in the region, with the highest values concentrated in coastal areas, the end of the continental shelf and some points in open waters, such as seamounts (Figures 4, 5).

The Ecological Relevance index has made it possible to identify the distribution of areas of high and very high ecological relevance, which cover **13 % of the marine surface of the Balearic Sea** and follow a heterogeneous pattern. Thus, in open waters (100–2,600 m) these areas represent 11.6 % of the total, while in coastal waters and continental shelf (from 0 to 100 m) they barely occupy 1.4 % of the surface area. The areas with the greatest ecological relevance coincide with those previously identified as having high or very high biodiversity and/or fishing resources, and include, among others, the Formentor peninsula, the island of Cabrera, the islets of Ponent, the north of Menorca, and the Menorca Channel. In open waters, the highest values are recorded on the seamounts, mainly Ausiàs March, Ses Olives, Émile Baudot, and Mount SSS (Figure 6).

Therefore, the conservation of the Balearic Sea requires identifying these areas of ecological relevance, which would provide a solid basis for developing strategies to strengthen the resilience and sustainability of its marine ecosystems, thus contributing to the fulfilment of international 10x30 conservation commitments and consolidating the region as a reference in marine management.



5. Limitations and recommendations

The results of this study are a first step towards the identification of areas of high and very high ecological relevance. However, this does not imply that these are the only relevant areas in the Balearic Sea, but rather that they are the only ones identifiable with the information available to date. Therefore, these results should be interpreted with caution. The lack of open access, the low spatial resolution of the information (especially in open waters), outdated information, or gaps in certain regions (e.g. Ibiza and Formentera), are some of the limitations we encountered in developing the proposed spatial indices in the whole study area.

Even so, the proposed methodology allows re-evaluating the indices with new information and incorporating new indicators to improve the precision and robustness of the results of ecological relevance. For example, the inclusion of pelagic diversity, the biomass recovery potential of fishery resources, or the location of climatic refuges would be essential aspects to consider within ecological relevance to progressively improve spatial planning and conservation of the essential marine ecosystems of the Balearic Sea from an ecological, economic, and social point of view.

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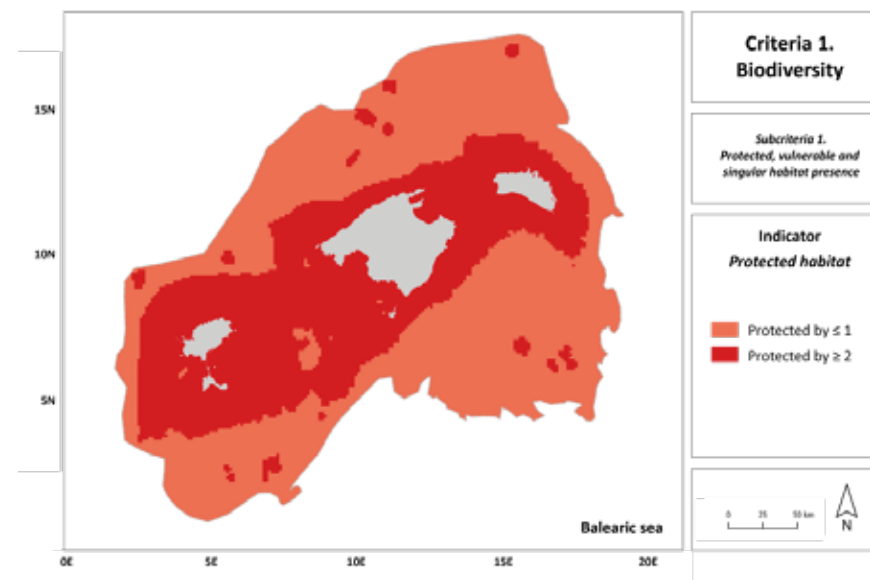
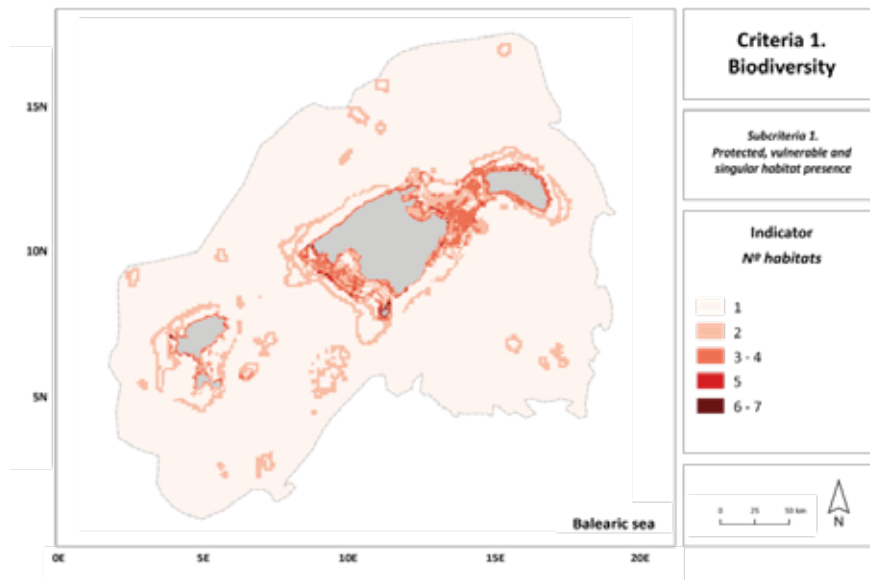
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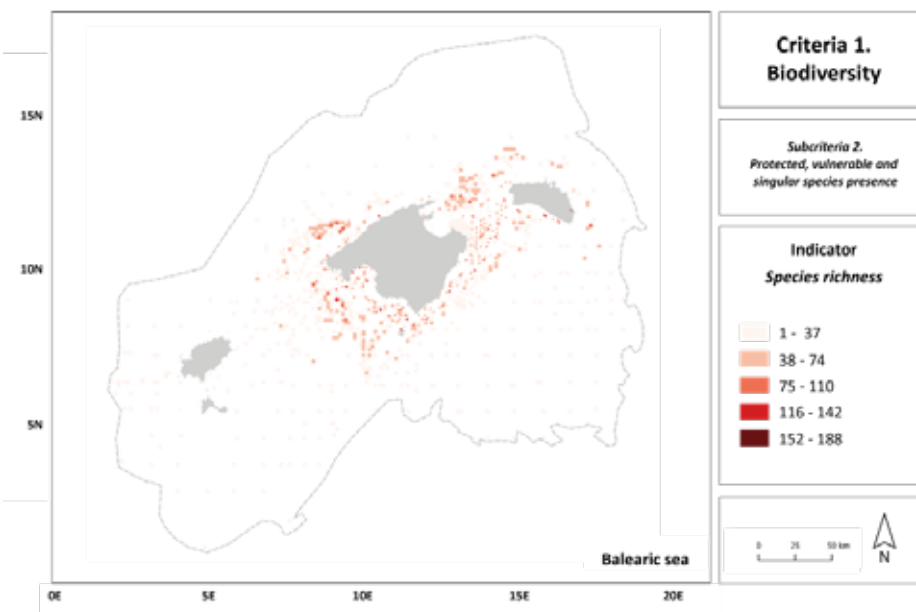
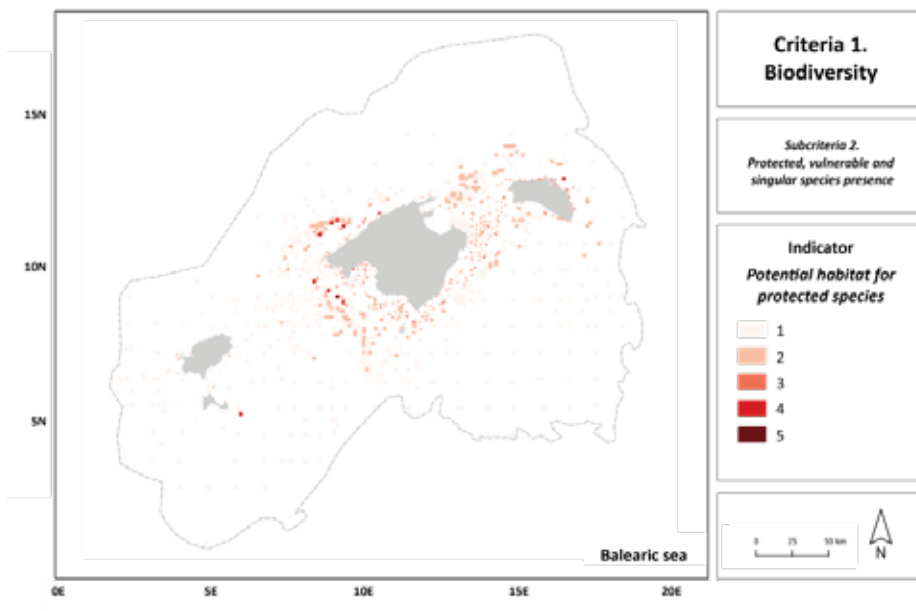
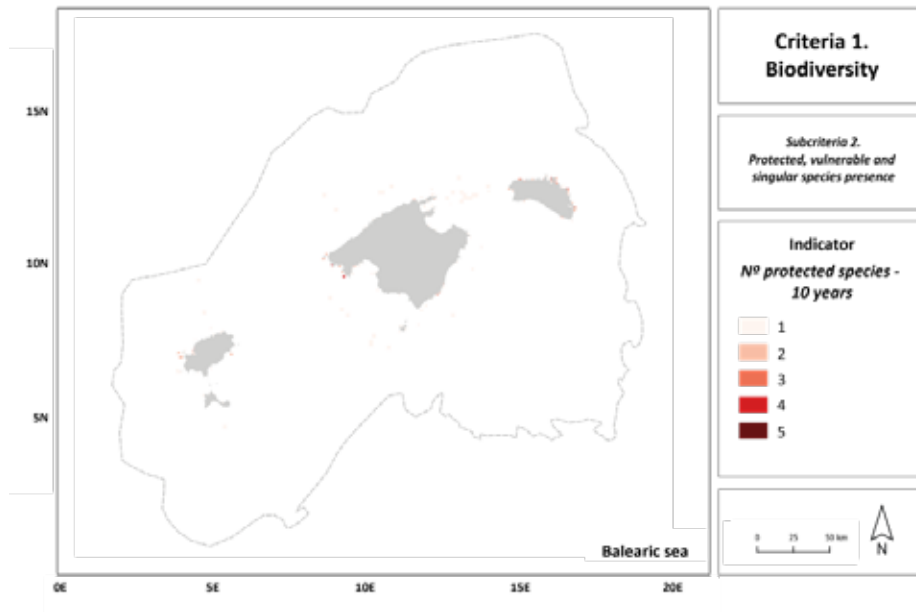
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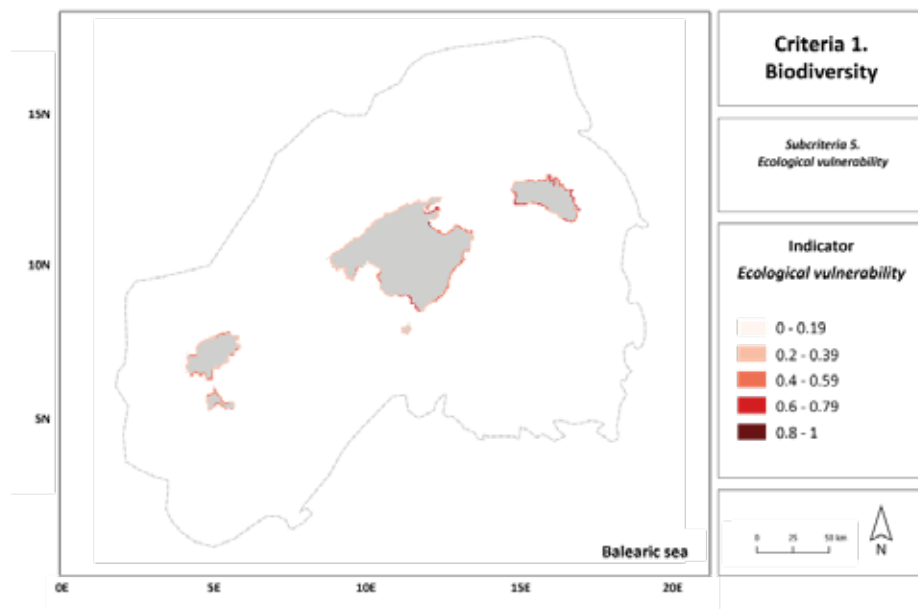
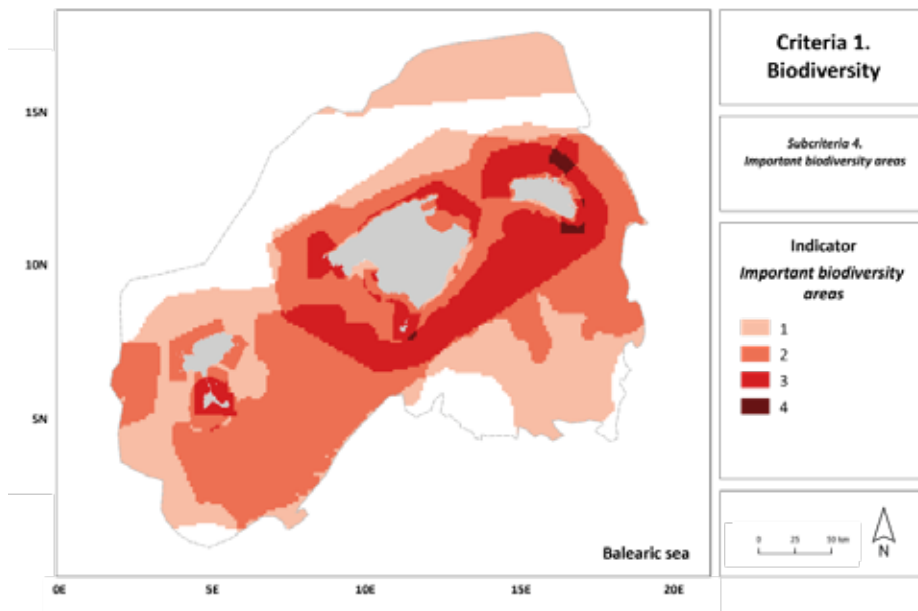
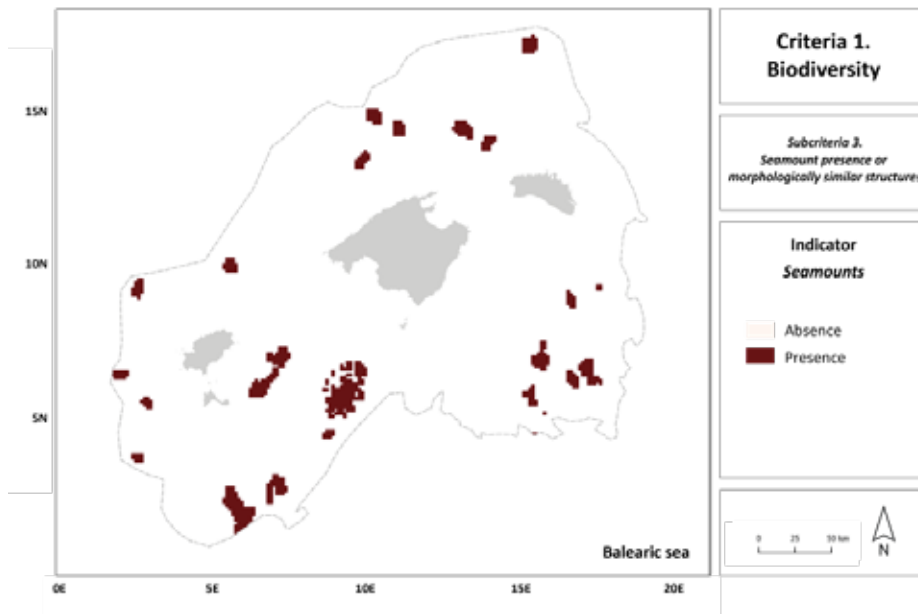
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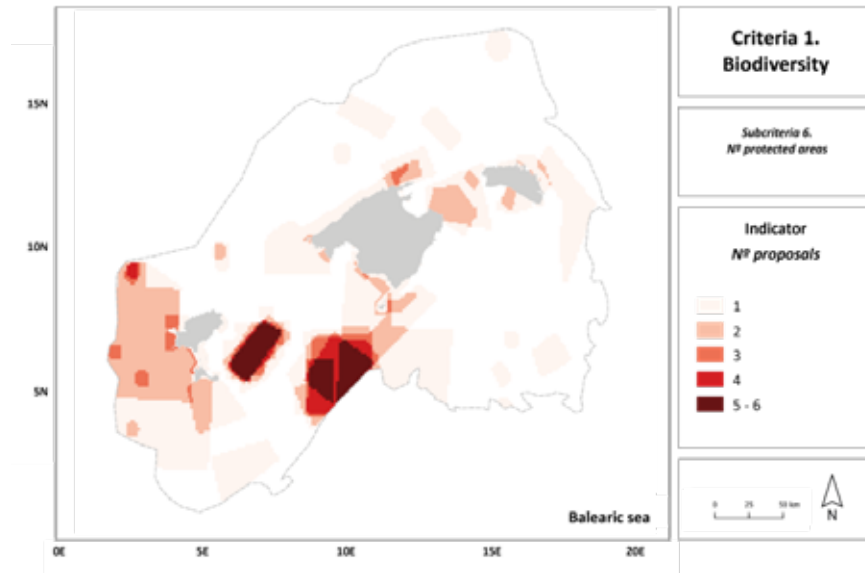
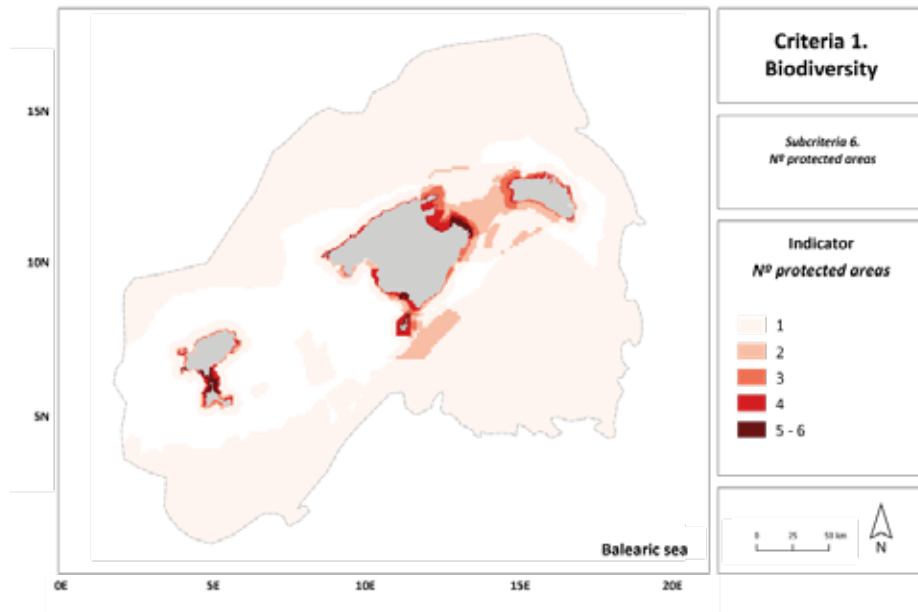
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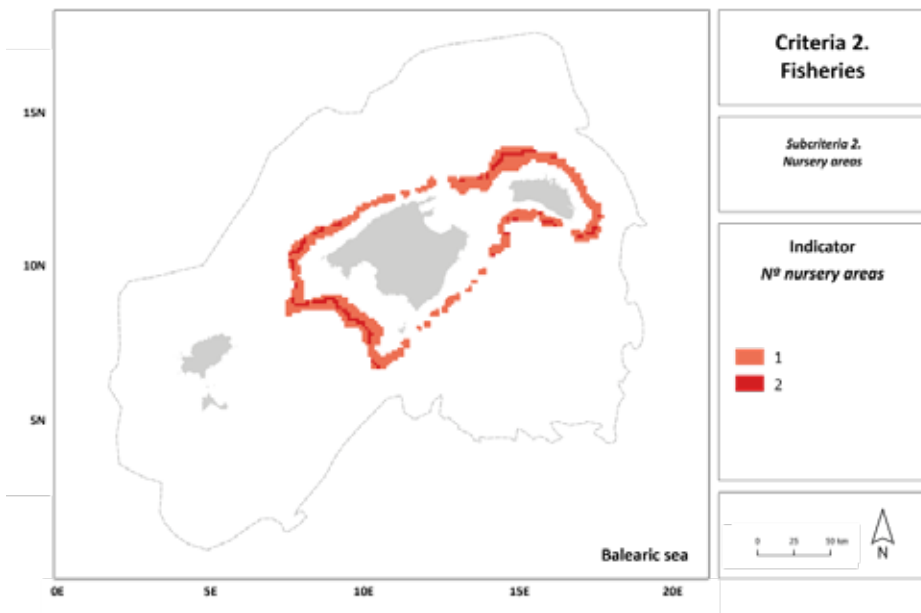
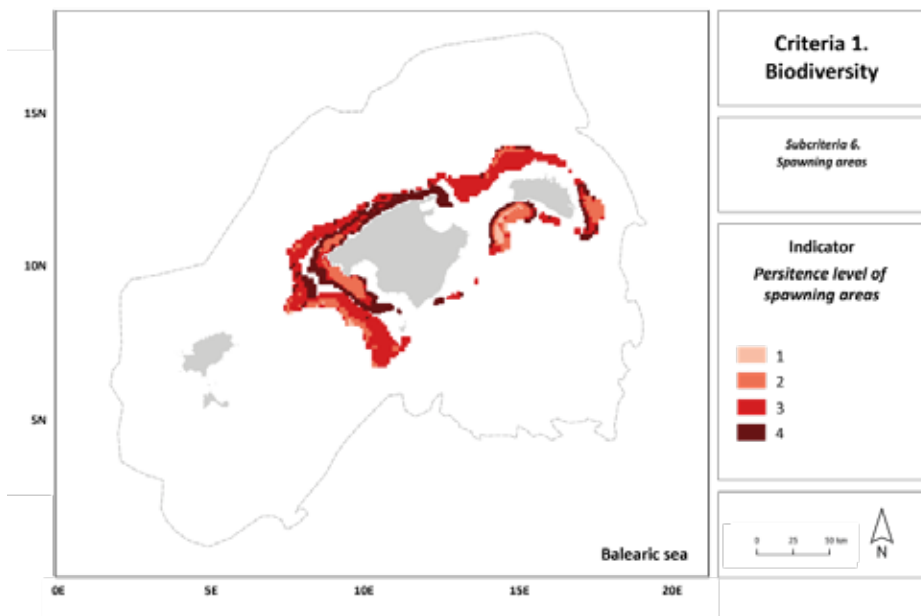
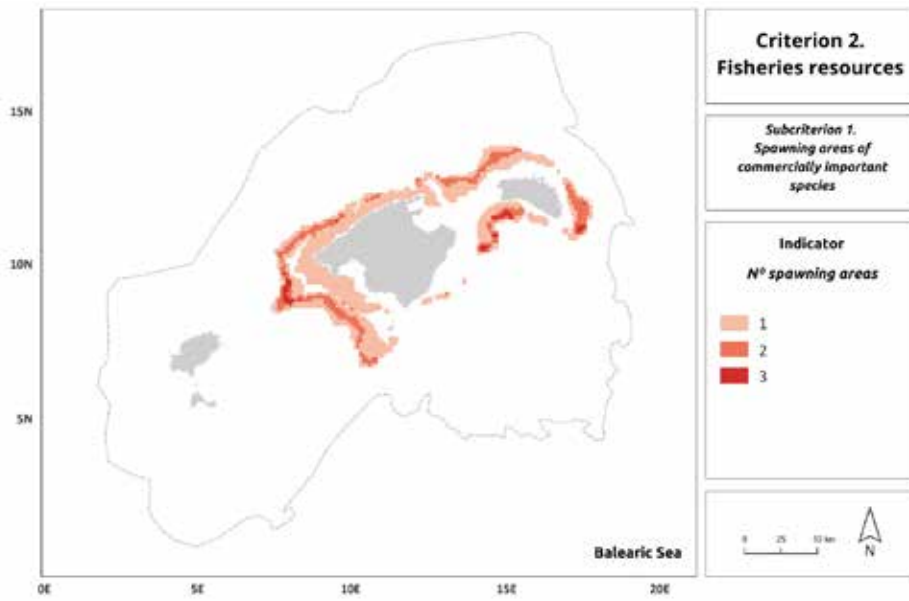
7. Annex I

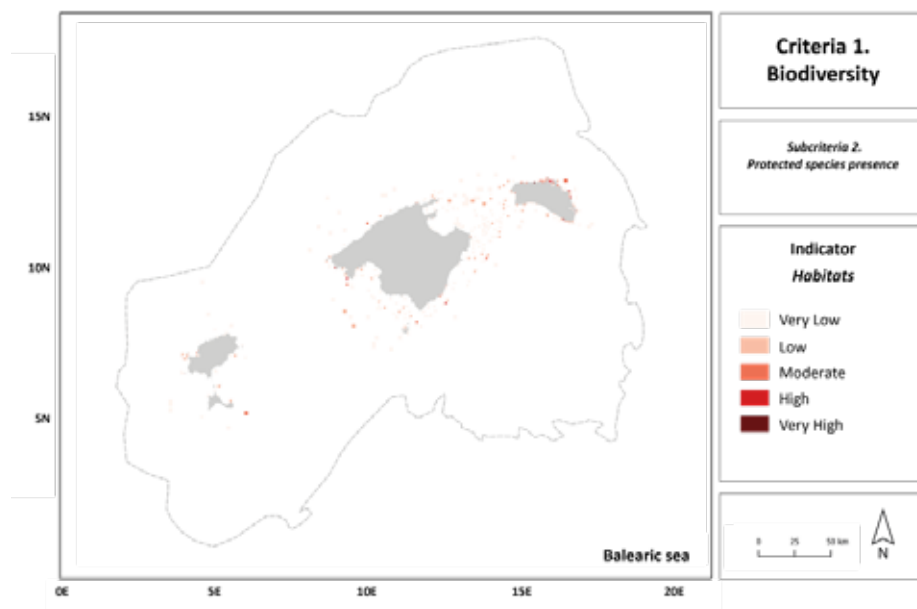
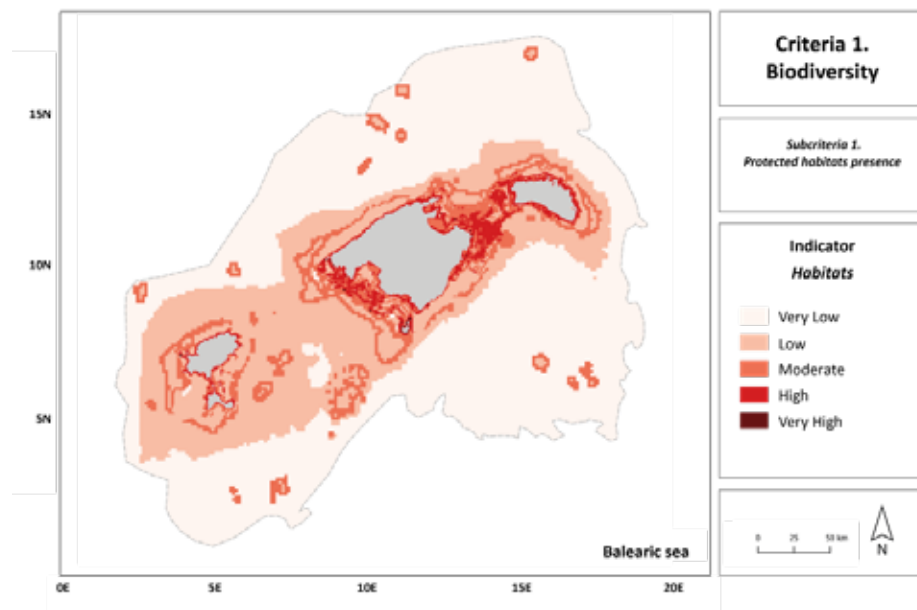
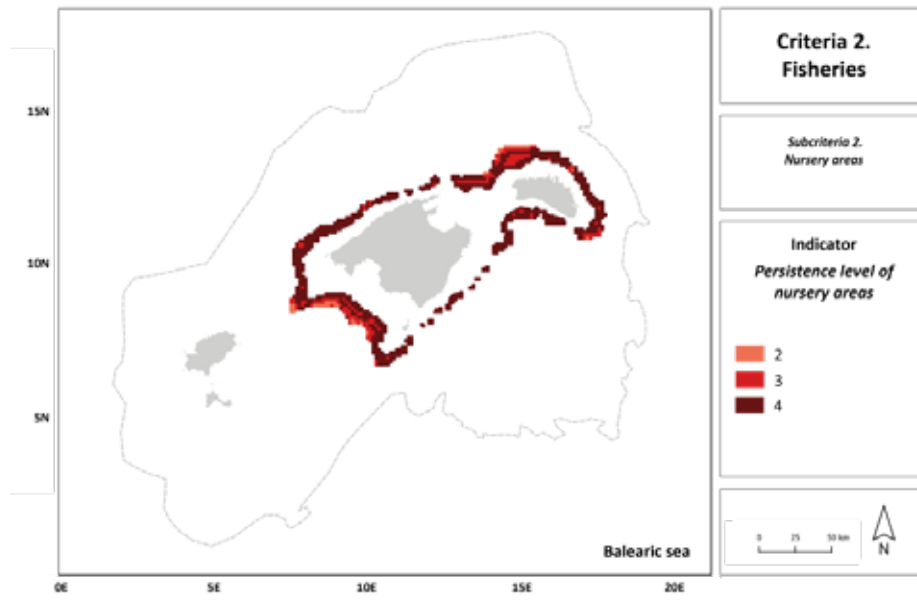


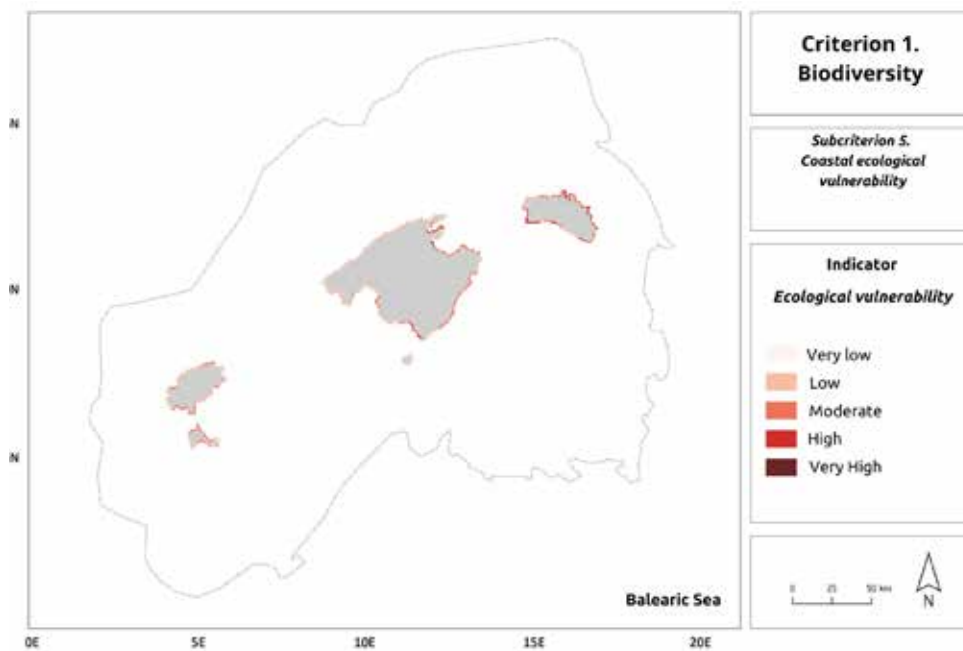
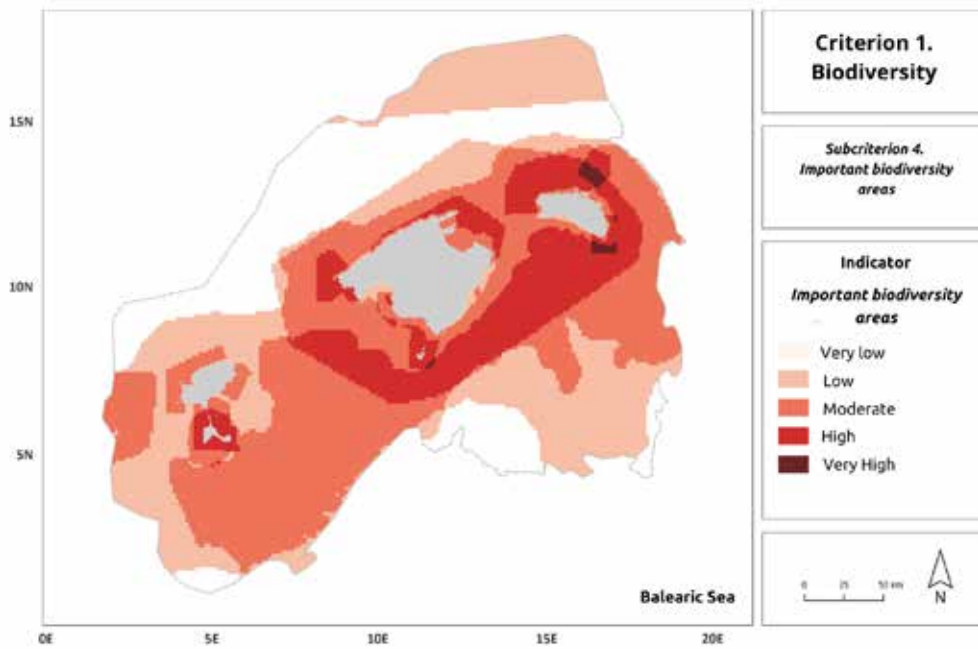
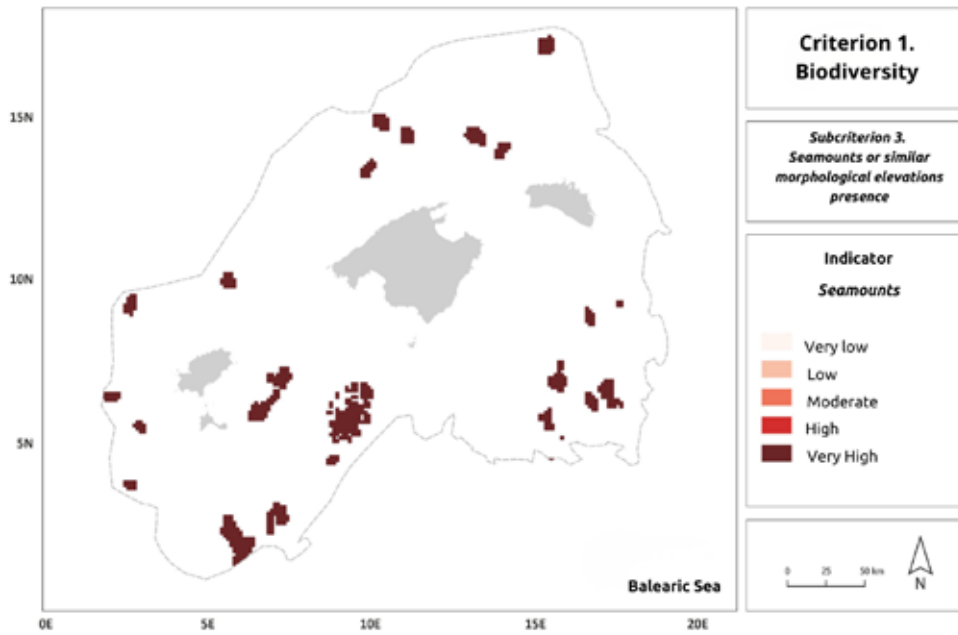


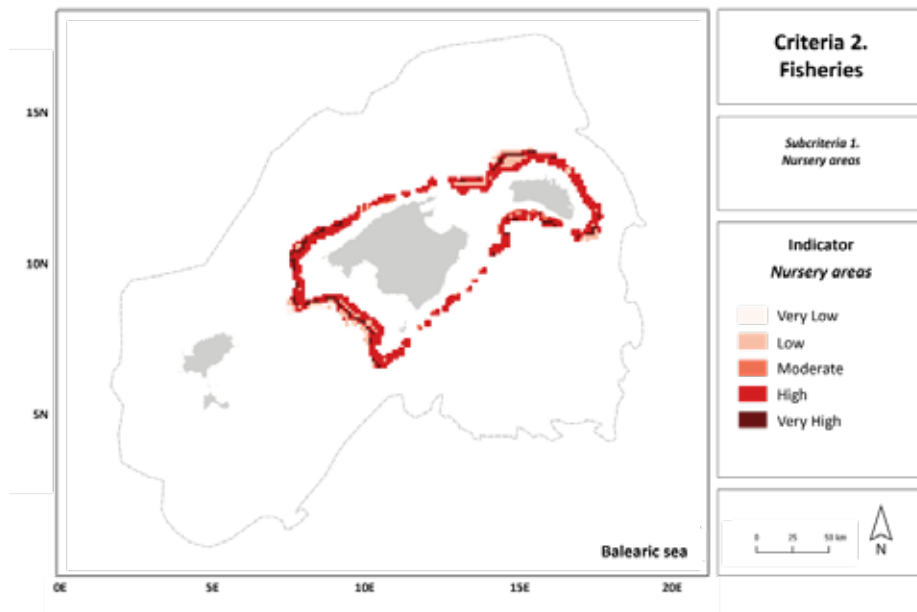
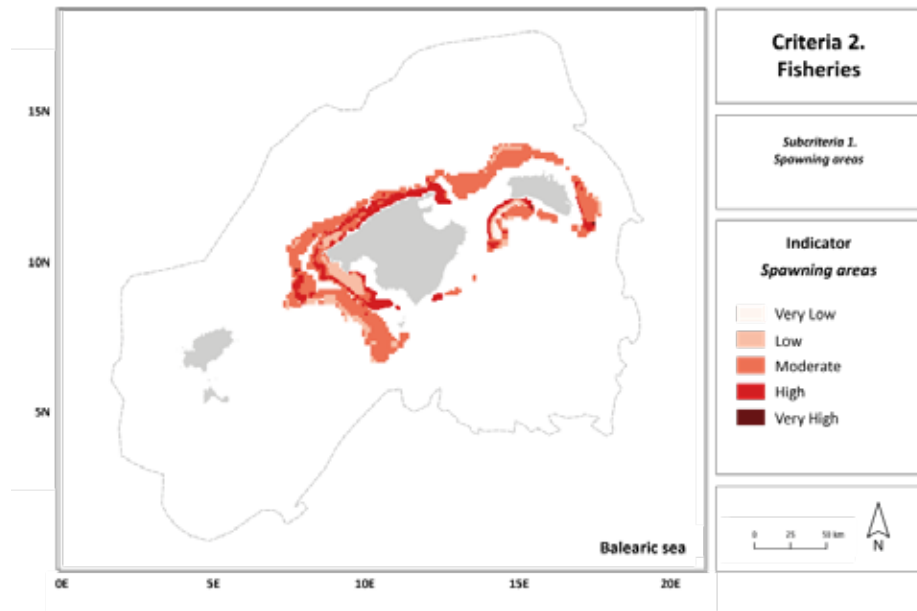
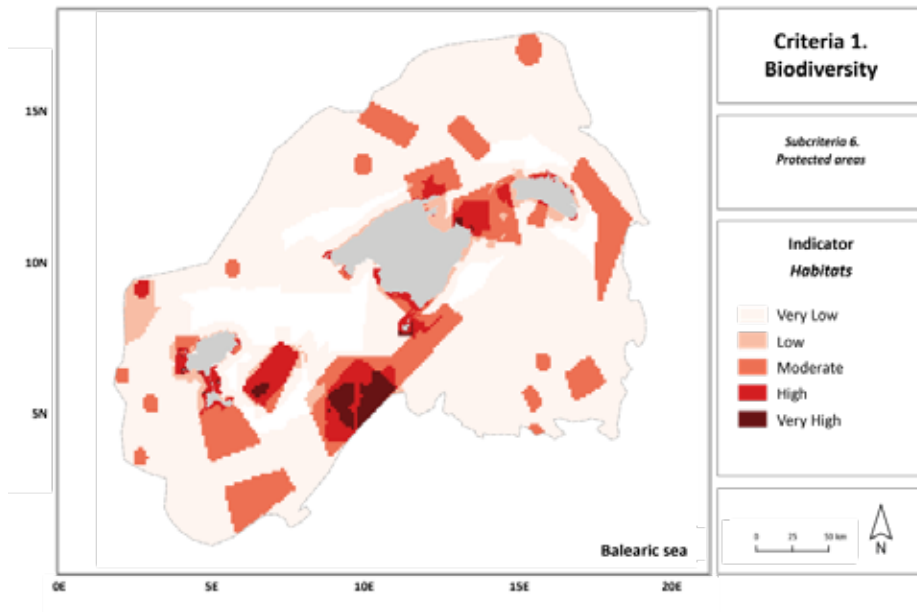


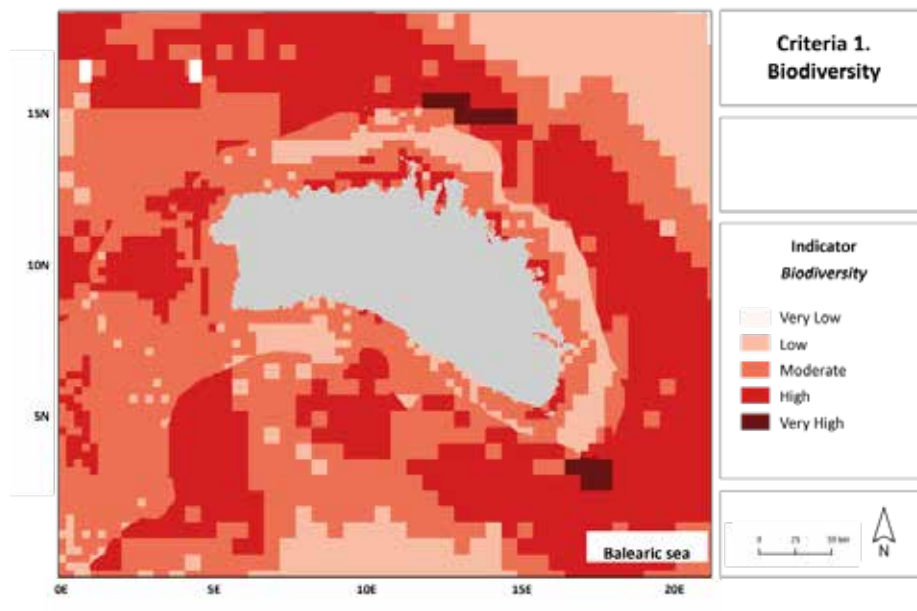
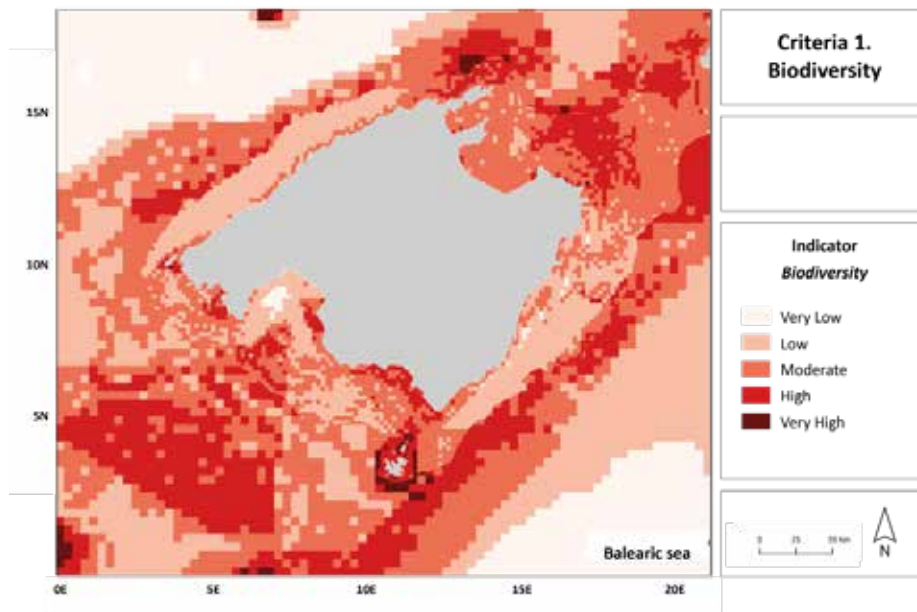
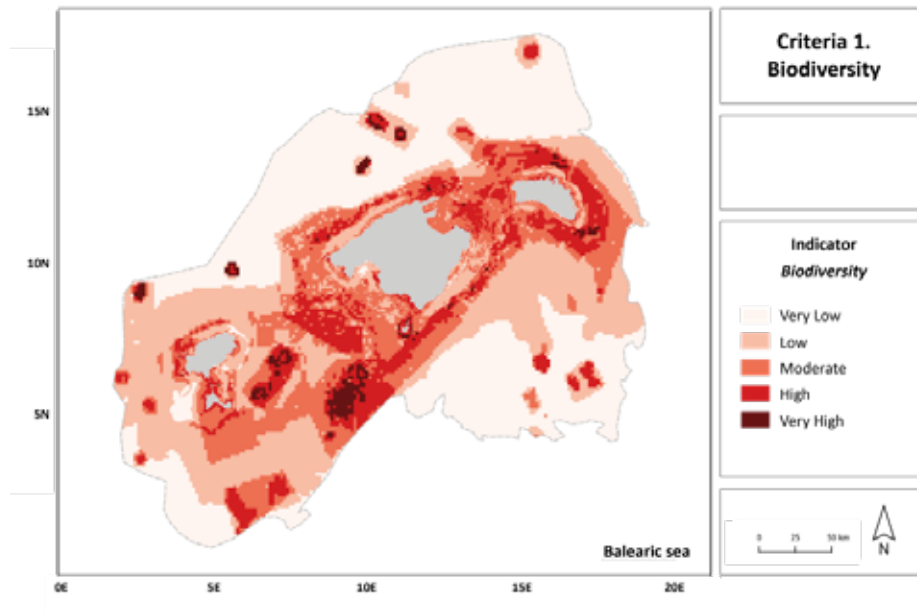


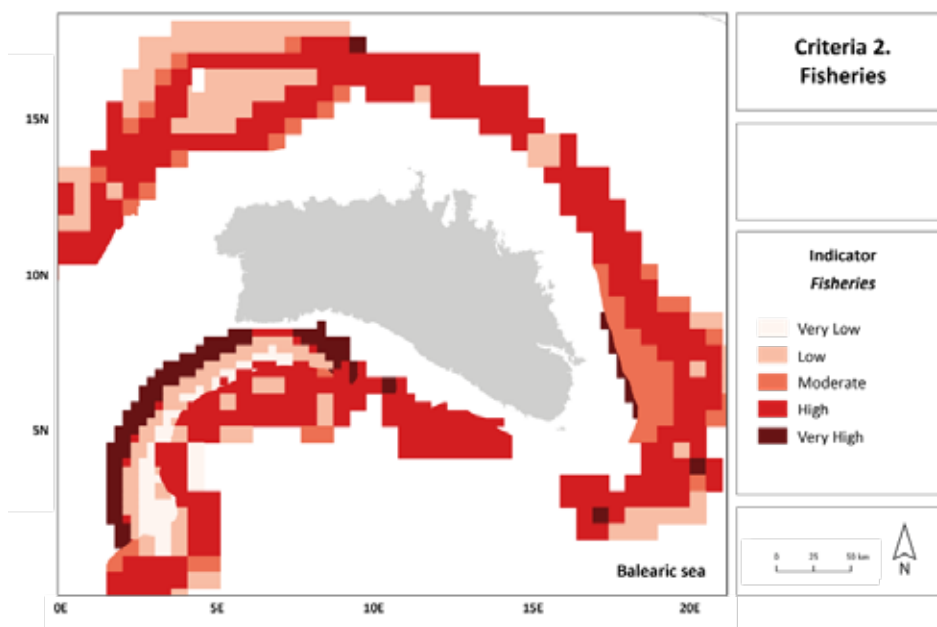
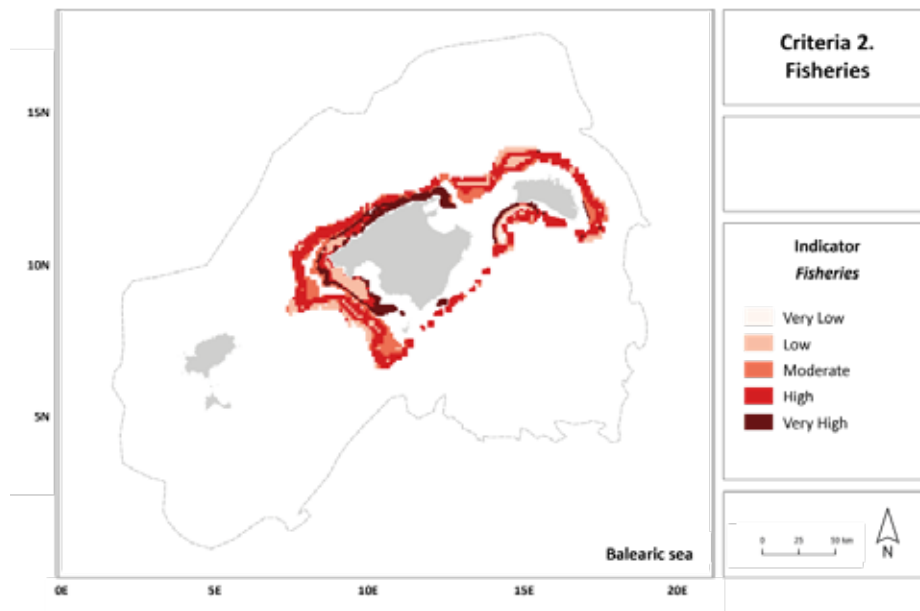
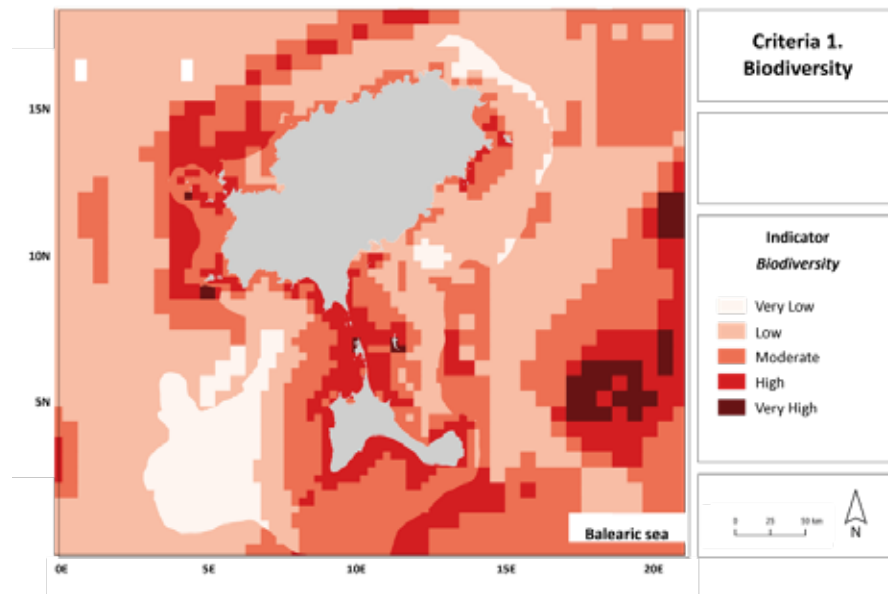


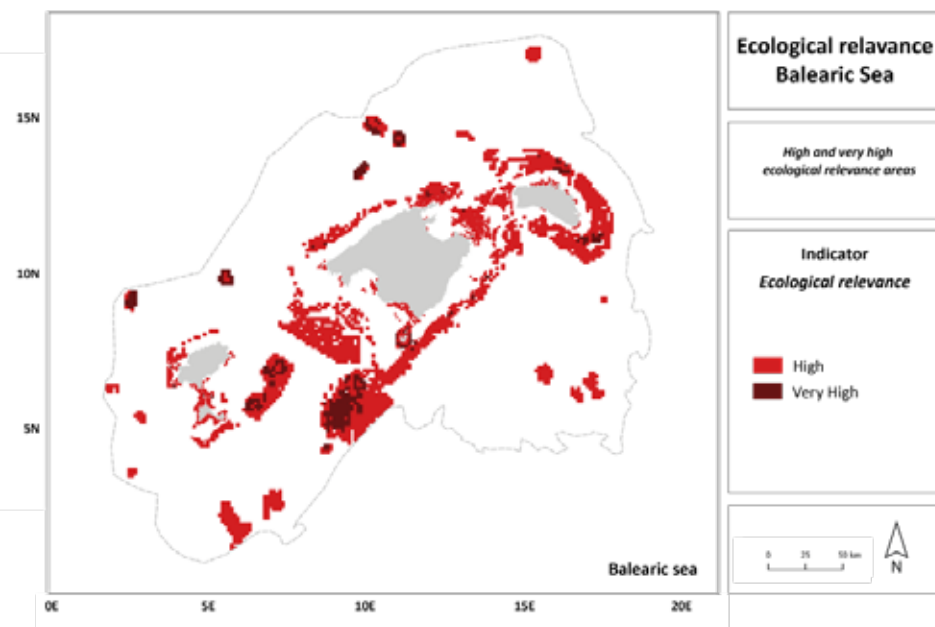
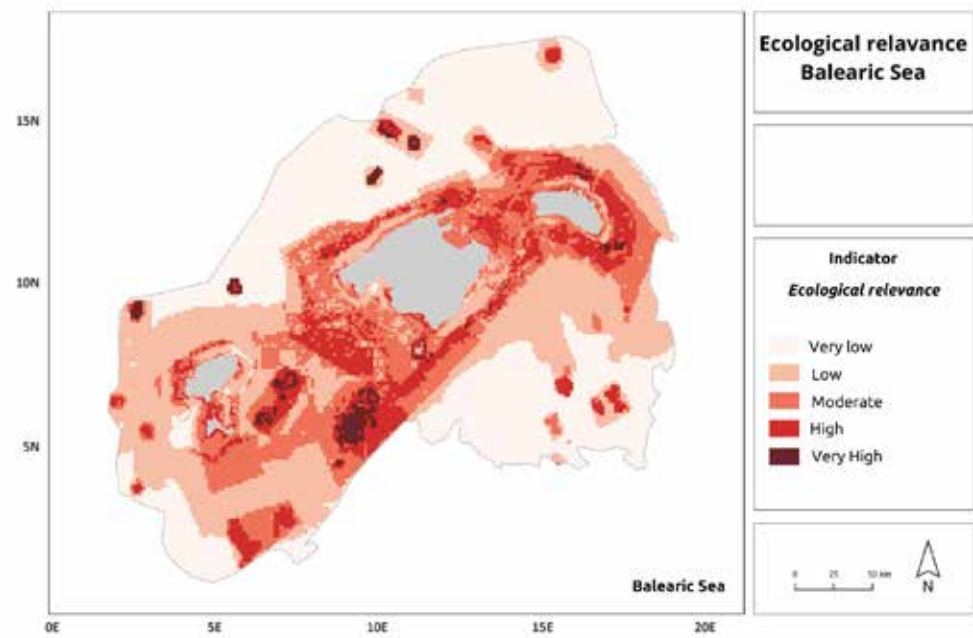
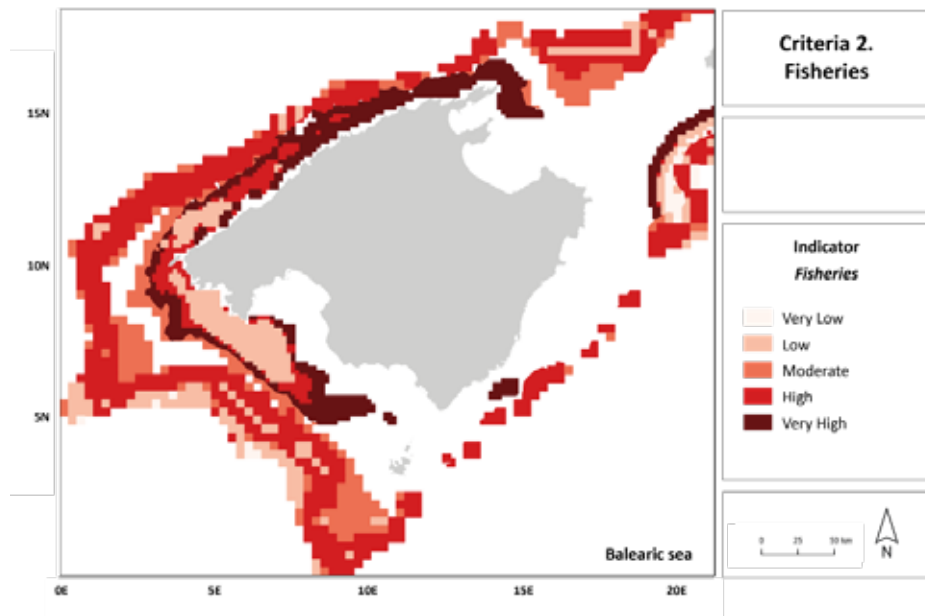


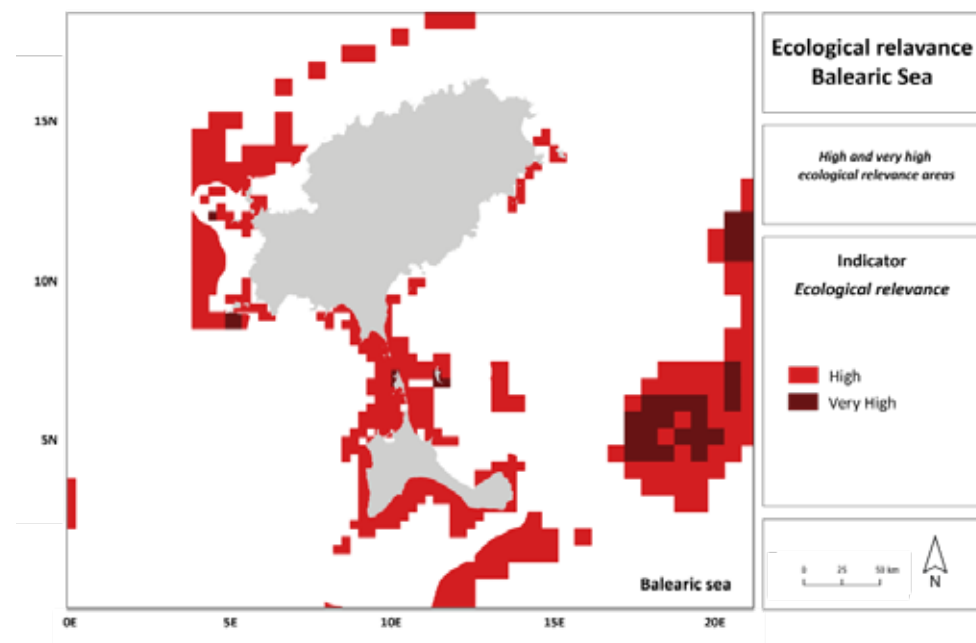
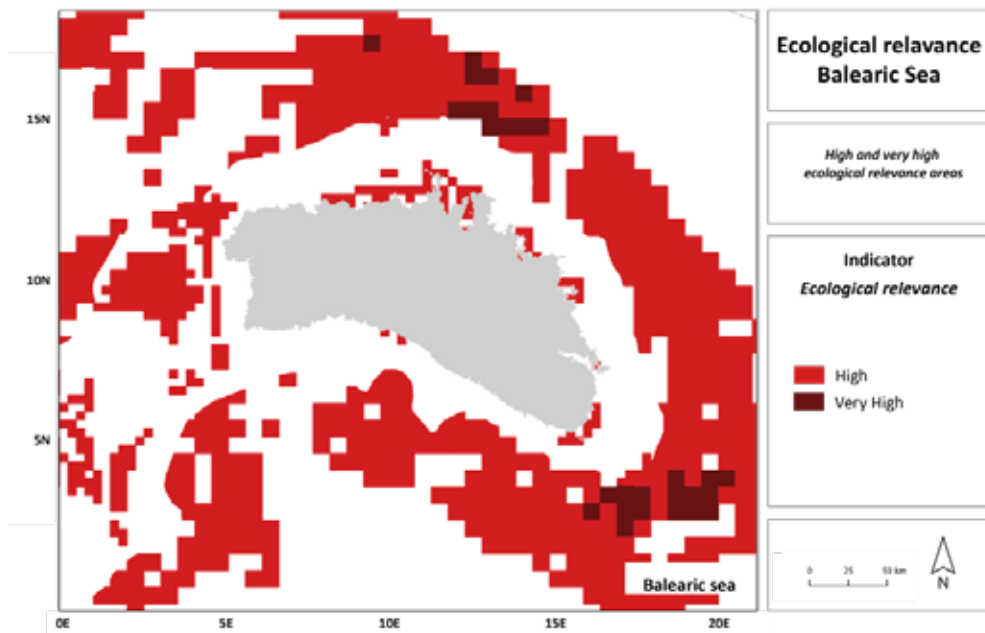












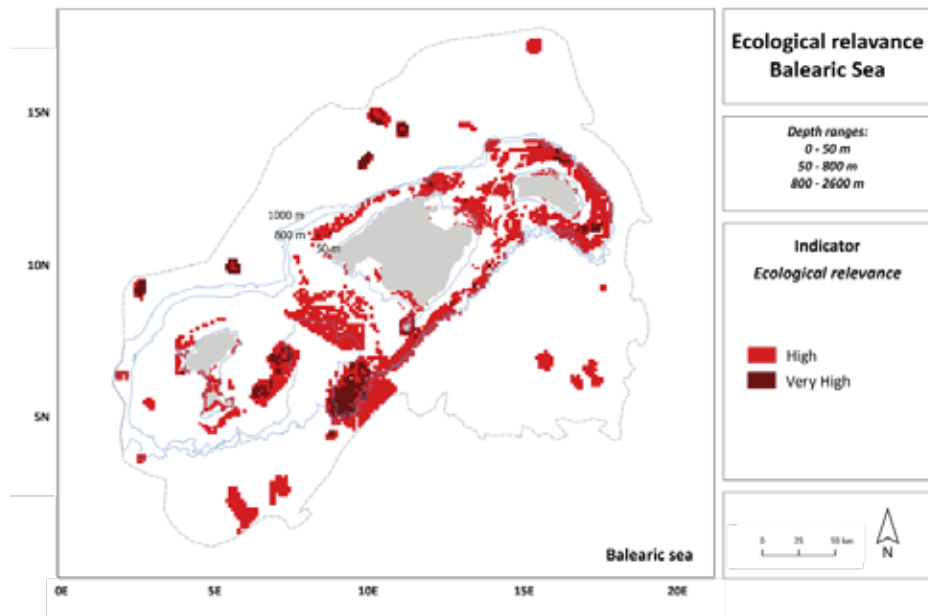
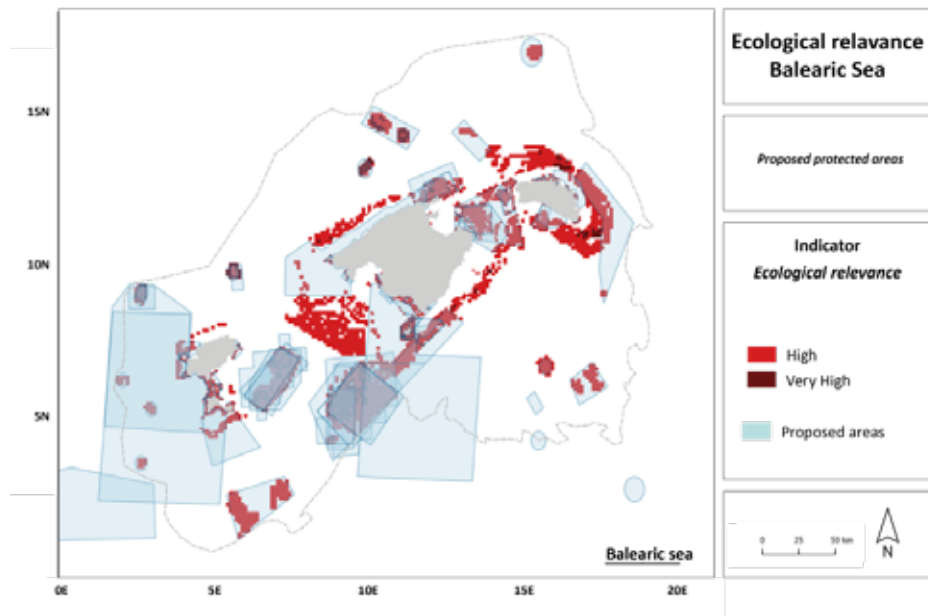
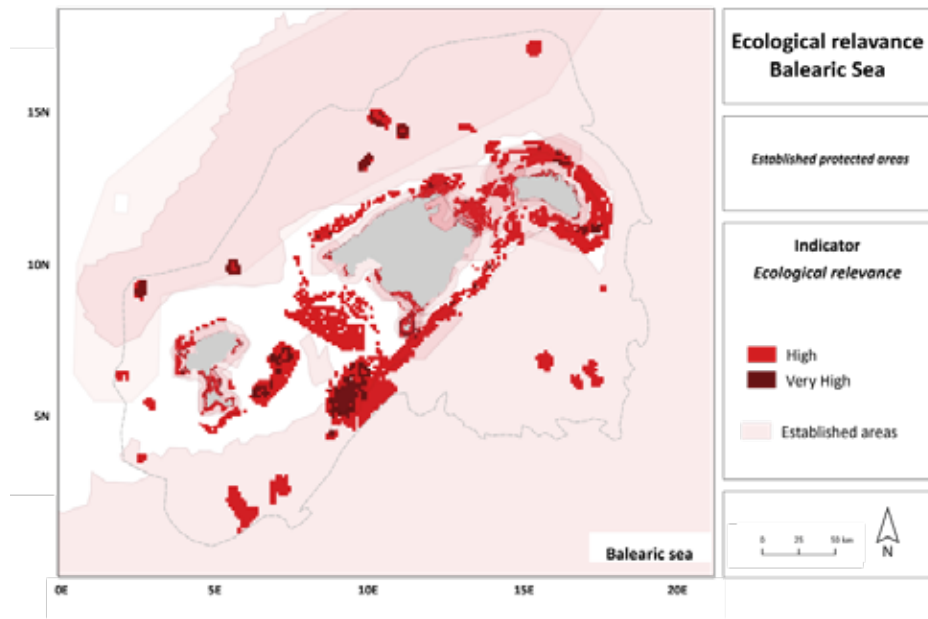


Table S1. Spatial information used for each of the indices developed.

Subcriterion/Index	Spatial information
Habitats	Mapping of marine habitats in the Balearic Islands: compilation of layers and benthic communities (Julià et al., 2019)
	Posidonia Atlas (CAIB, 2020)
	Bionomic mapping of Cabrera (OAPN, 2020)
	EUSeaMap 2023 Broad-Scale Predictive Habitat Map for Europe
Species	Selection of 20 protected species (OBIS, GBIF)
	Marine biodiversity atlas of the Balearic Sea (IEO-CSIC, 2011)
Seamounts	IdelB bathymetry
	DTM EMODnet2022
Important areas for biodiversity	Important Marine Mammal Areas (IMMA, IUCN)
	Important Shark and Ray Areas (ISRA, IUCN)
	Key Biodiversity Areas (KBA, IUCN)
	Ecologically or Biologically Significant Marine Areas (EBSA, CBD)
Ecological vulnerability	Ecological vulnerability (Ribera Plan, 2014; MITECO)
Protection	Natura 2000 Network (Habitats Directive)
	Fisheries Restricted Areas (FRAs, General Fisheries Commission for the Mediterranean – GFCM)
	Specially Protected Areas of Mediterranean Importance – SPAIM (Barcelona Convention)
	Marine Reserves of Fishing Interest – RMIP (Network of Marine Protected Areas in Spain – RAMPE)
	Marine Reserves of Fishing Interest – RMIP (Spanish Network of Marine Protected Areas – RAMPE)
	<i>Posidonia</i> Decree (Decree 25/2018, of 27 July, on the conservation of <i>Posidonia oceanica</i> in the Balearic Islands (BOIB No. 93 of 28 July 2018))
	Proposal for Marine Protected Areas (Ballesteros, 2022)
	Proposals for Sites of Community Importance (LIFE IP INTEMARES, 2021)
	Proposal for Sites of Community Importance (MITECO, 2023)
	Proposal for Restricted Fishing Areas (OCEANA, 2010)
	Proposal for Marine Protected Areas (OCEANA, 2012)
Proposals for marine refuges (OCEANA, 2023)	
Breeding and spawning areas	Essential Fish Habitats of the Balearic Islands (MediSeH project, 2011)

Table S2. Categorisation within the semi-quantitative scale of each of the indicators developed.

Subcriterion/Index	Indicator	Semi-quantitative scale				
		Very low (1)	Low (2)	Moderate(3)	High (4)	Very high (5)
Habitats	Main habitat*	Coral, Pre-coral, Rocky, Maërl, Detrital, <i>Laminaria</i> , Sedimentary, Meadows, <i>Caulerpa</i>				
	Number of habitats	1	2	3-4	5	6-7
	Protected habitat			Protected by ≤ 1	Protected by ≥ 2	
Species	Number of protected species - 10 years	1	2	3	4	5
	Potential habitat of protected species	1	2	3	4	5
	Species richness	1-37	38-74	75-110	111-142	143-188
Seamounts	Seamounts ¹					Presence
Important areas for bio-diversity	Important areas for biodiversity		1	2	3	4
Ecological vulnerability	Ecological vulnerability ²	0-0.19	0.2-0.39	0.4-0.59	0.6-0.79	0.8-1
Protection figures	Number of protection figures	1	2	3	4	5-6
	Number of proposals	1	2	3	4	5-6
	Ballesteros protection levels (2022)		Special Conservation Area	Marine Protected Area	No-Fishing Area	Integral Reserve
Breeding areas	Number of breeding areas			1	2	
	Level of persistence of breeding areas			2	3	4
Spawning areas	Number of spawning areas		1	2	3	
	Level of persistence of spawning grounds		1	2	3	4

* The "main habitat" indicator is for information purposes only and therefore the scale has not been applied.

^{1,2} indicators used only in open waters, and coastal waters and surface shelf, respectively.

Table S3. Grouping of habitats applied to the bionomic mapping of the Balearic Sea, following the nomenclature of Templado *et al.* (2012).

Code	Habitat	Grouping
0305130201	<i>Caulerpa prolifera</i> (0305130201)	<i>Caulerpa</i>
03020104	Coral reef with algae dominance, without fucal or laminarial (03020104)	Coral reef
03020225	Coral reef with dominance of invertebrates (03020225)	Coral reef
030405	Infralittoral and circalittoral biogenic detrital bottoms (030405)	Detrital
03040507	Infralittoral and circalittoral biogenic detrital bottoms with <i>Phyllophora crispa</i> / <i>Osmundaria volubilis</i> (03040507)	Detrital
03040510	Biogenic detrital bottoms with <i>Halopteris filicina</i> (03040510)	Detrital
03040514	Infralittoral and circalittoral detrital bottoms dominated by invertebrates (03040514)	Detrital
03040515	Infralittoral and circalittoral muddy detrital bottoms (03040515)	Detrital
03040508	Biogenic detrital bottoms with <i>Laminaria rodriguezii</i> (03040508)	<i>Laminaria</i>
03040504	Maërl beds (03040504)	Maërl
0304050604	Maërl beds dominated by <i>Peyssonnelia spp</i> (0304050604)	Maërl
03040511	Infralittoral and circalittoral biogenic rubble (mollusc shells) bottoms (03040511)	Maërl
03040513	Infralittoral and circalittoral rhodolith and gravel bottoms dominated by invertebrates (03040513)	Maërl
030513C	Mixed meadows of <i>Cymodocea nodosa</i> and <i>Cystoseira spp.</i> (030513C)	Meadows
030513A	Mixed meadows of <i>Cymodocea nodosa</i> and <i>Caulerpa prolifera</i> (030513A)	Meadows
030504	<i>Zostera noltii</i> (030504)	Meadows
030509	<i>Cymodocea nodosa</i> (030509)	Meadows
030511	<i>Cymodocea nodosa</i> and <i>Zostera noltii</i> (030511)	Meadows
030513B	Mixed meadows of <i>Zostera noltii</i> and <i>Caulerpa prolifera</i> (030513B)	Meadows
030512	<i>Posidonia oceanica</i> (030512)	Meadows
030513	Seagrass beds and rhizomatous green algae (030513)	Meadows
030513	<i>Posidonia oceanica</i> meadows on dead vegetation (rhizome) (030513)	Meadows
03051202	<i>Posidonia oceanica</i> reef (03051202)	Meadows
03051203	Dead rhizome of <i>Posidonia oceanica</i> (03051203)	Seagrass beds
030104	Rocky bottoms dominated by sciaphilous and hemisciaphilous algae. Pre-coral facies (030104)	Pre-coral
-	Coast - Emerged rock	Rocky
0301A	Rocky bottoms with photophilic algae (0301A)	Rocky
0301C	Photophilic algae on rock with <i>Posidonia oceanica</i> (0301C)	Rocky
0302	Rocky circalittoral floor and other hard substrates (0302)	Rocky
030202	Circalittoral rock dominated by invertebrates (030202)	Rocky
03020206	Gorgonian forests on circalittoral rock dominated by invertebrates (03020206)	Rocoso
03020223	Circalittoral rock without concretions dominated by invertebrates (03020223)	Rocky
03020224	Circalittoral rock silted up by sediments (03020224)	Rocky
040102	Sediment-clogged batial rock (040102)	Rocky
040104	Deep sea cliffs, walls and rocky slopes (040104)	Rocky
03010	Hard or rocky substrate (03010)	Rocky
03040	Soft or sedimentary substrate (03040)	Sedimentary
030401	Infralittoral and circalittoral pebbles and gravel (030401)	Sedimentary
030402	Infralittoral and circalittoral sands and muddy sands (030402)	Sedimentary
0304021704	Muddy sands and bays with red algae (<i>Alsidium corralinum</i>) (0304021704)	Sedimentary
03040223	Unstable infralittoral sediments (03040223)	Sedimentary
030403A	Infralittoral and circalittoral mud and sandy mud (030403A)	Sedimentary
030403B	Port sediment (030403B)	Sedimentary
0701	Artificial hard substrate (0701)	Artificial
070103	Artificial reefs (070103)	Artificial

Tabl3 S4. Proportion of the different values of the index of ecologically relevant areas and ecologically relevant hotspots (the total of high and very high ecological relevance) with respect to the total surface area (i) of the corresponding zone and (ii) of the Balearic Sea.

Area	Semi-quantitative scale					Hotspot
	Very low (1)	Low (2)	Moderate (3)	High (4)	Very high (5)	
Balearic Sea: 0–2,600 m	36.8%	30.4%	19.8%	11.3%	1.7%	13%
Coastal waters and shallow shelf: 0–100 m	5.2 0.4%	32.7 3%	47 4.4%	14.7 1.4%	0.3 0.03%	15 1.4%
Open waters: 100–2,600 m	40.1 36.4%	30.2 27.4%	17 15.4%	10.9 9.9%	1.9 1.7%	12.7 11.6%
Depth range: 0–50 m	2 0.06%	22.1 0.6%	55.8 1.6%	19.5 0.6%	0.6 0.02%	20.1 0.6%
Depth range: 50–800 m	1.7 0.5%	32.6 9.2%	36.9 10.4%	25 7.1%	3.9 1.1%	28.9 8.2%
Depth range: 800–1,000 m	2.6 0.2%	45.1 3.6%	35.5 2.8%	15.2 1.2%	1.7 0.1%	16.9 1.3%

* Percentages are presented in relation to Zone | Balearic Sea.



MED30 