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'STRENGTHENING INTERNATIONAL OCEAN DATA THROUGH THE EU'S OCEAN DIPLOMACY WITH CHINA'

EMOD-PACE (EMODNET PARTNERSHIP FOR CHINA AND EUROPE)

D4.5 – Final report on the "Marine Resource-Environment Carrying Capacity and Spatial Development Suitability" approach application to Europe, showing the Bay of Biscay as an example

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SUMMARY

The EMODPACE project was approved by the European Commission, with the aim of promoting international ocean governance between EU and China, and support the implementation of global commitments, by making ocean marine data and data products more easily accessible and by providing better data and data products. In this context one of the objectives of EMODPACE is to compare European and Chinese models by analysing the applicability of each side models for ecosystem vulnerability. Hence, applying the Chinese Marine Resource-Environment Carrying Capacity and Spatial Development Suitability approach to a European sea (in this case, the Bay of Biscay) and looking for potential comparison with the Maritime Spatial Planning Directive (MSPD) and the Marine Strategy Framework Directive (MSFD) approaches in Europe, covers the abovementioned objective. The Bay of Biscay was selected because the abundance of data availability and previous transboundary management in the application of the MSPD and MSFD. China has carried out many years of research and application in the fields of carrying capacity, and the official methodology of 'Marine Resource-Environment Carrying Capacity (MRECC) and Spatial Development Suitability' developed and applied for MSP in coastal and marine area was adapted to the European context, in terms of the MSFD and the MSPD. The Chinese official methodology was applied to the Bay of Biscay. The methodology involves three different steps: (i) an evaluation of the marine ecological protection (MEP), which includes species and habitats (i.e., biodiversity protection); (ii) an evaluation of the Spatial Development Suitability, identifying the needs for marine activities development and the current use of the sea space; and (iii) an ecological risk identification and the evaluation of the MRECC, by intersecting results from (i) and (ii). After collating information for 31 species of interest (fish, reptiles, mammals and birds), seven habitats (seagrass, seaweeds, saltmarshes, fishery growing areas, tidal flats, estuaries and other unique habitats), marine protected areas and eight current human activities at sea (aquaculture, ports, ocean energy facilities, shipping, aggregate extraction and dredging, fisheries, military areas and tourism and recreation), they were aggregated and intersected (ecological data vs human activities), and the ecological risk was determined. Since the total area covered by Marine Protected Areas and Marine Ecological Protection importance areas is 135,372 km^2, the available carrying capacity for marine development activities within the Bay of Biscay is 229,266 km^2. Weighting the marine ecological protection and human activities, the importance areas increase and the available carrying capacity decreases 0.2%, being now 228,637 km^2. Hence, it has been shown that this methodology is applicable to Europe, but more applications in different areas are needed, as well as improve the information for some species and habitats, in order to obtain more accurate results.

Table of Contents

Table of illustrations

Figures

Tables

1 Introduction

Historically, activities at sea have been diverse, including fishing, shipping, or leisure, among many others (Kleingärtner, 2018). Nowadays, both historical and new human activities at sea (the so-called ‘blue economy’; EUMOFA (2020)) are rapidly increasing, resulting in cumulative pressures on marine ecosystems (Borja et al., 2020). After the second World Ocean Assessment (United Nations, 2021a, 2021b), those human pressures are impacting coastal ecosystems (e.g. seagrasses, mangroves and coral reefs), land- and sea-based activities are introducing pollutants to the sea (e.g. nutrients, metals, pesticides, pharmaceuticals, litter, microplastics or noise), overfishing has a pervasive effect on the trophic web, and on top of those the gases released into the atmosphere are driving warming, acidification and sea-level rise, which are threatening biodiversity, ecosystem services delivery and even human health (Pörtner et al., 2021). Hence, although the ocean is the life-support system of our planet, it seems to be near its carrying capacity (United Nations, 2021a, 2021b).

To fight against these problems, different management responses have been implemented at global, international, or national scales. Hence, the United Nations Sustainable Development Goals (United Nations, 2016), tries to find an equilibrium between growth and sustainability of human activities. In the case of marine systems, these can be achieved through marine spatial planning (MSP) of human activities, under an ecosystem-based management approach, in which the activities are undertaken in a sustainable way (Ehler and Douvere, 2009). In this context, many countries around the world have implemented MSP (Frazão Santos et al., 2019; Chalastani et al., 2021), based on specific legislation. For example, in Europe, the Maritime Spatial Planning Directive (MSPD; European Union, 2014) drives the future development of activities at sea, while at the same time good environmental status must be achieved in all regional seas, under the Marine Strategy Framework Directive (MSFD; European Commission, 2008). Other countries, such as China, have followed different spatial planning approaches, such as the Major Marine Functional Zoning Plan (MMFZP) and Marine Functional Zoning (MFZ) (Tang et al., 2020) or the "multi-plan integration", in which various types of spatial planning are integrated into one framework (Feng et al., 2016). These approaches also include the evaluation of resource-environment carrying capacity and spatial development suitability (abbreviated as "double evaluation") and provide a scientific basis for maritime spatial planning (Yue et al., 2020). By considering natural resources, environment and ecology double evaluation provides a relative suitability measure for ecological conservation and economic development (i.e., activities sustainability), as well as maximum carrying capacity assessments for each economic activity (Yue et al., 2020).

The relationships between economic growth and environmental quality, as well as the link between economic activities and the carrying capacity and resilience of the environment, have been largely discussed for decades (Arrow et al., 1996). The methodologies to determine the carrying capacity have been applied to diverse human activities at sea, including among others aquaculture (Duarte et al., 2003; Cai and Sun, 2007; Byron et al., 2011; Filgueira et al., 2015), beach uses (Epelde et al., 2021), tourism (Pearce and Kirk, 1986; Hughes and Furley, 1996; Han, 2018; Sha, 2020), harbours (Li et al., 2018a), land-uses (Li et al., 2018b), recreation (Shokri and Mohammadi, 2021), or to multiple coastal activities (Di et al., 2007; Fuju et al., 2011; Liu et al., 2020).

As the ocean has become one of the main areas of development in Europe and in China, including ocean science and technology, ocean economy, ocean space, ocean environment and ecosystem health and protection, the cooperation between Europe and China on ocean issues has increased. Following high-level conferences and forums during the EU-China Blue Year 2017, the EU and China signed a Blue Partnership for the Ocean in 16 June 2018, which marked the beginning of a new phase of strategic EU-China ocean relations. The shared objective of the Partnership is to ensure effective ocean governance for the conservation and sustainable use of the oceans and their resources. In this context, the EMODPACE project was approved by the European Commission, with the aim of promoting international ocean governance between EU and China, and support the implementation of global commitments, by making ocean marine data and data products more easily accessible and by providing better data and data products. In this context one of the objectives of EMODPACE is to compare European and Chinese models by analysing the applicability of each side models for ecosystem vulnerability. Hence, applying the Chinese double evaluation approach to a European sea and looking for potential comparison with the maritime spatial planning approach in Europe, could be considered as a good candidate to cover the abovementioned objective. To facilitate this, an Annex with guidelines has been added.

2 Methodology

2.1 Case study: The Bay of Biscay

The Bay of Biscay is in the north-East Atlantic Ocean, between North-West France (Britany) and North-West Spain (Galicia) (Borja et al., 2019a). The limits of the bay are Cape Finisterre, at 43°N, in Galicia (NW Spain), and 48°N, in Brest (NW France) (Lavín et al., 2006). In total, the Bay occupies around 175,000 km^2 (Borja et al., 2019a). This area was selected as a case study, due to the abundance of data available, as well as the availability of previous transboundary management information on the application of the MSFD (Cavallo et al., 2018) and the MSPD (Pinarbasi et al., 2020).

The bay is a well-differentiated geomorphological unit, orientated towards the NW, which created a long fetch and high oceanographic dynamics, in terms of winds, currents and waves (Borja et al., 2019a). The abyssal basin represents 50% of the total surface, with a mean depth of 4,800 m (Lavín et al., 2006). The continental shelf in the south of the bay is narrow (12-30 km), being wider in the French coast (in the north has >150 km wide). The continental slope is very pronounced (slope of 10%–12%). This slope is cut by numerous canyons, which have generally narrow, steep-sided, linear, and sinuous channels, the most conspicuous being the Capbreton Canyon, where the 1,000 m isobath is found only 3 km from the coast (Lavín et al., 2006; Galparsoro et al., 2020).

To establish the geographical boundaries of the case study, we have considered different sources of information (Figure 1): (1) the corresponding Food and Agriculture Organization (FAO) fishing subarea (27.8)[1] and the International Council for the Exploration of the Sea (ICES) ecoregion ("Bay of Biscay and the Iberian Coast")[2], (2) marine regions and subregions under the MSFD, specifically the boundaries for the region "North east Atlantic Ocean" and subregion "Bay of Biscay and the Iberian Coast"[3], and (3) the coastal and transitional water bodies extracted from the reference spatial data sets of the Water Framework Directive (WFD) (European Commission, 2000)[4]. Considering these sources of information, the limits of the study area have been established as follows:

- Marine limits in the south-west of the study area: the area corresponding to FAO fishing areas 27.8.c and 27.8.d.2 and located inside the MSFD subregion "Bay of Biscay and Iberian Coast".
- Marine limits in the north of study area: the limits of the FAO fishing areas 27.8.a and 27.8.d.2.
- Terrestrial limits in the south and east of the study area: MSFD subregion "Bay of Biscay and Iberian Coast" and coastal and transitional waters according to the WFD. The limits have been adjusted using both sources to achieve maximum coverage.

Additionally, a buffer was established along the coast to cover the marine-terrestrial interface: five kilometres buffer around the coast and one kilometre buffer around the transitional water bodies. Figure 1 shows the case study area limits, including the buffer zone.

In total, the Bay of Biscay case study area covers 369,762 km^2, an area much larger than the extension of the bay abovementioned, since it has been extended offshore, to accommodate the regions from

[1] https://data.apps.fao.org/map/catalog/srv/eng/catalog.search#/metadata/ac02a460-da52-11dc-9d70-0017f293bd28 (Access: 14/01/2022)
[2] http://gis.ices.dk/geonetwork/srv/eng/catalog.search#/metadata/4745e824-a612-4a1f-bc56-b540772166eb (Access: 14/01/2022)
[3] https://www.eea.europa.eu/data-and-maps/data/europe-seas-1 (Access: 14/01/2022)
[4] https://www.eea.europa.eu/data-and-maps/data/wise-wfd-spatial-3 (Access: 14/01/2022)

FAO and ICES, and inshore, and to include the transitional areas and the coastal buffer zone. Only 3% (10,638 km^2) of the area is terrestrial, and corresponds to the buffer area, while 97% (358,651 km^2) is marine or coastal (including transitional waters). The case study area falls within the marine and terrestrial boundaries of Spain and France. The terrestrial limits of the case study area in Spain correspond to its Northern Atlantic coast, around four regions: the coasts of the Basque Country, Cantabria, Asturias and (partially) Galicia. In France, the case study area limits correspond to three regions: Nouvelle Aquitaine, Pays de la Loire and (partially) Bretagne (Figure 1).

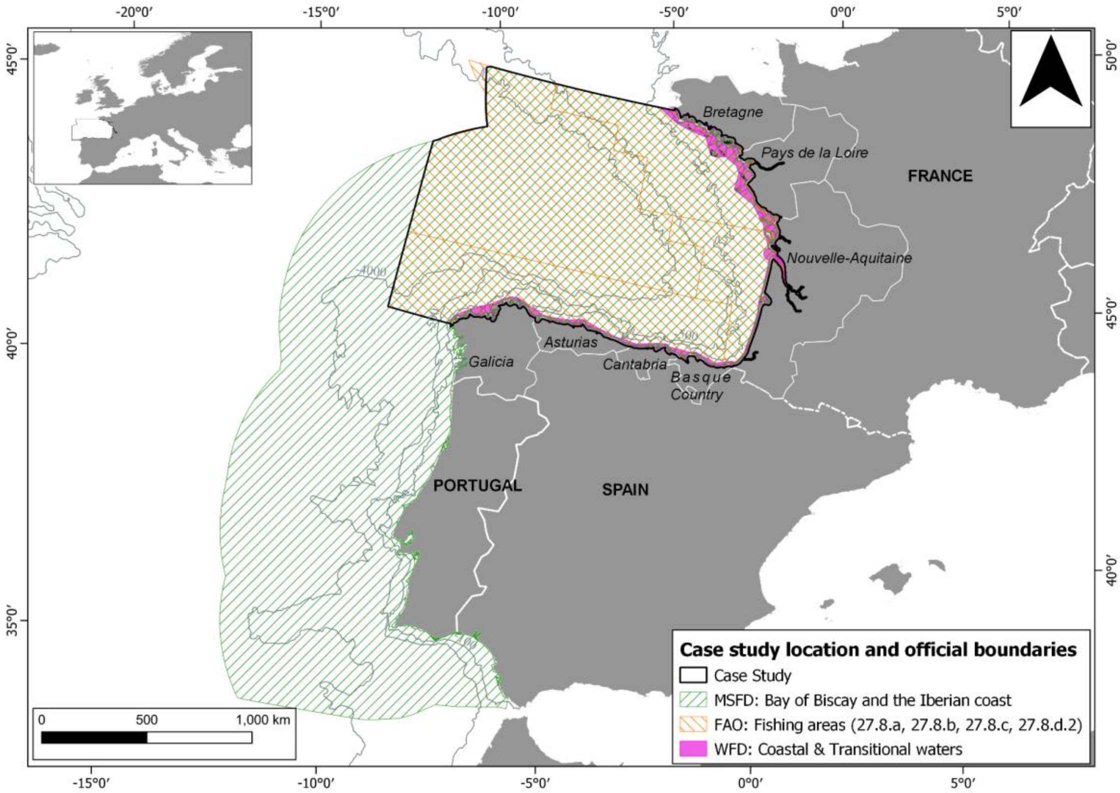

Figure 1. Location of the case study in the European context and other boundaries: Marine Strategy Framework Directive (MSFD), Food and Agriculture Organization (FAO) fishing areas, and Water Framework Directive (WFD).

To analyse the information in a standardized way, the study area polygon was intersected with the European Environmental Agency (EEA) reference grid (1x1 km)[5]. All the cells that are totally or partially inside the study area were selected. It is important to note that an area in the north-west corner of the study area polygon was excluded from analysis as it does not intersect the EEA grid (Figure 2). A total of 364,638 cells were selected: 349,703 were marine (including estuaries, lagoons, coastal and offshore waters), 6,865 terrestrial and the remaining 8,070 were partially terrestrial and marine.

[5] https://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-2 (Access: 14/01/2022)

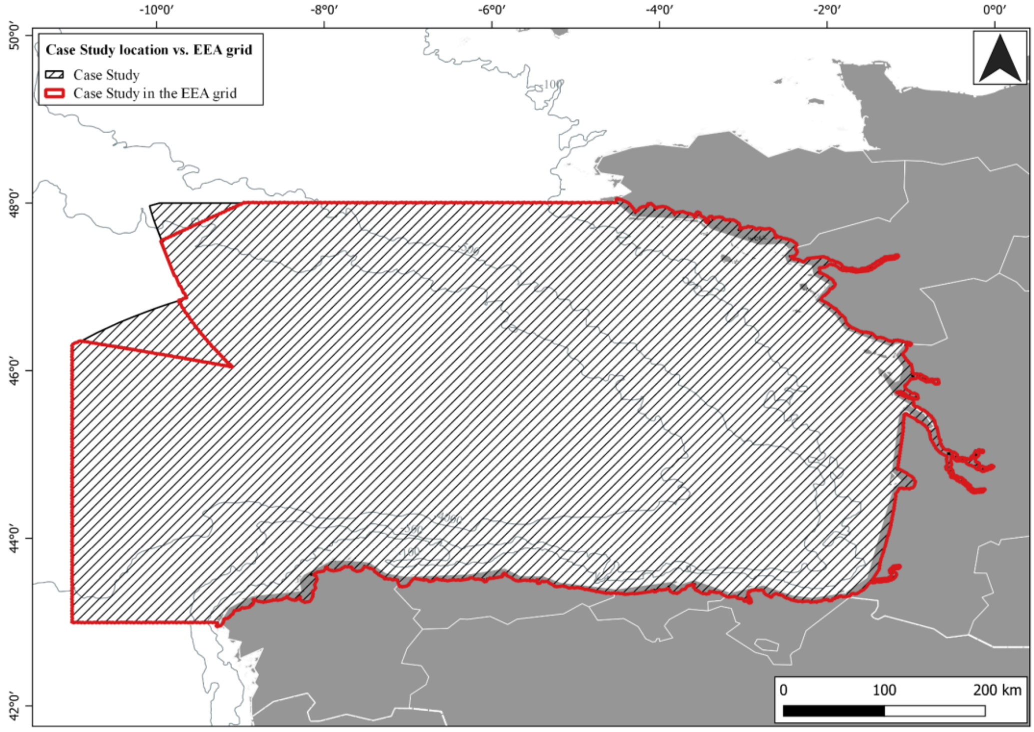

Figure 2. Original boundaries of the Bay of Biscay case study area (in black), and adapted boundaries (in red) to fit with the European Environment Agency (EEA) 1x1 km reference grid.

2.2 Adaptation of the double evaluation methodology to Europe: data collection

China has carried out many years of research and application in the fields of carrying capacity, such as Liaoning Province (Di et al., 2007), Xiamen Bay (Liao et al., 2013), Dongtou Islands (Ma et al., 2017), the offshore Yangtse River area (Song and Du, 2019), or Fujian Province (Zhao et al., 2021), among others. Recently, in 2020, an official methodology of double evaluation was developed and was applied for maritime spatial planning in coastal and marine areas. Technical text provided by the National Marine Data and Information Service (NMDIS), and translated from Chinese to English, can be seen in Annex 1: Technical guidance on evaluation of Marine Resource-Environment Carrying Capacity and Spatial Development Suitability (official version). There, the Marine Resource-Environment Carrying Capacity (MRECC) refers to "*the maximum and feasible volume of marine human activities which can be supported by marine resources and environment in a given sea area, which is associated with (based on) levels of development, economy and technology, production and lifestyle and goals for ecological protection*."

However, due to the differences in the terminology, elements and data availability, the methods used in the Chinese version were adapted to the European context, in terms of the MSFD and the MSPD. The document included in Annex 2: Technical guidance on evaluation of Marine Resource-Environment Carrying Capacity and Spatial Development Suitability (adapted version),is an adapted translation of the official methodology and it has been used as a basis for the application of the approach to the Bay of Biscay.

The methodology involves three different steps:

1) An evaluation of the marine ecological protection (MEP method), which includes species and habitats (i.e., biodiversity protection);
2) An evaluation of the needs for marine activities development and use of the sea space;
3) A risk identification and evaluation of the MRECC, by intersecting results from (1) and (2).

The application of these steps to the Bay of Biscay is described below.

2.2.1 Evaluation of the marine ecological protection

The first step of the double evaluation methodology requires the evaluation of the MEP function, which includes: (i) the assessment of ecosystem services, carried out estimating the provision of marine biodiversity maintenance and coastal protection; and (ii) the assessment of the sensitivity of marine ecosystems, evaluated based on vulnerability to coastal erosion and sand loss, including different indicators (Table 1).

Firstly, the three components (maintenance of marine biodiversity, coastal protection and vulnerability) are individually assessed. Secondly, the results are integrated to identify the relevant ecological functional areas.

2.2.1.1 Marine biodiversity maintenance area

The MEP method evaluates the marine biodiversity maintenance area at three different levels: species, habitats, and genes. The method’s requirements and how these were adapted to the European context are explained below and summarized in Table 1.

At the **species level**, the MEP requires the identification of the “species distribution areas” by means of two indicators: population size and importance of distribution area. The adaptation of the methodology to the European context and the data availability assessment were based on two sources of information: (i) a list of species of interest, and (ii) their spatial distribution within the case study area.

To create the list of species of interest, the ‘OSPAR List of Threatened and/or Declining species’[6] within OSPAR Region IV (OSPAR Agreement 2008-06)[7], and the ‘Reference List for the Marine Atlantic Region’ of the Habitats Directive[8] were used. Data on the spatial distribution of those species were obtained from the International Union for Conservation of Nature (IUCN) Red Lists[9], and the bird species distribution data were requested to Birdlife International[10]. Spatial data were obtained for 31 (19 fish, 2 reptiles, 6 mammals, 4 birds) of the 33 species of interest within the case study (Table 2).

[6] Only the species included in the OSPAR Agreement 2008/06 as under threat and/or declining in Region IV.
[7] https://www.ospar.org/work-areas/bdc/species-habitats
[8] Only the species included in the reference list as present in Spain and/or France: https://www.eionet.europa.eu/etcs/etc-bd/activities/marine-atlantic-region.pdf (Access: 15/06/2021)
[9] https://www.iucnredlist.org/resources/spatial-data-download (Access 10/05/2021)
[10] http://datazone.birdlife.org/species/requestdis (Data request: 17/05/2021)

Table 1. Evaluation of marine ecological protection (MEP) at species and habitats levels, as described in the Marine Resource-Environment Carrying Capacity (MRECC) methodology. "Level", "Area" and "Specific Indicator" columns were extracted from Table 1 of the MRECC Method (Annex 2). "Sources", "Description" and "Link" columns describe the information sources used to adapt the MRECC methodology to the Bay of Biscay case study. IUCN: International Union for Conservation of Nature; OSPAR: Oslo-Paris Convention; BD: Birds Directive; HD: Habitats Directive; WFD: Water Framework Directive; WCMC: World Conservation Monitoring Centre; WISE: Water Information Centre for Europe.

Level	Area	Specific indicators	Sources	Description	Link
Species Level	Species distribution area	Population size	OSPAR Agreement 2008/06 & Reference List for the Marine Atlantic Region (Habitats Directive)	Identification of species of interest	https://www.ospar.org/work-areas/bdc/species-habitats https://www.eionet.europa.eu/etcs/etc-bd/activities/marine-atlantic-region.pdf
		Importance of distribution area	IUCN spatial information & Birdlife International	Spatial distribution of species of interest	https://www.iucnredlist.org/ http://datazone.birdlife.org/species/requestdis
Habitat Level	Seagrass bed	Habitat area and coverage	WFD Report (2016)	Angiosperm status in coastal water bodies	https://www.eea.europa.eu/data-and-maps/data/wise-wfd-4/wise-wfd-database-1/wise-wfd-database
	Seaweed habitats	Habitat area	EMODnet Seabed Habitats	Location of infralittoral rock, extracted from the broad-scale seabed habitats map EUSeaMap (2019)	https://www.emodnet-seabedhabitats.eu/access-data/download-data/?linkid=eusm_2021_atlantoarctic,eusm_2021_baltic,eusm_2021_blacksea,eusm_2021_mediterranean
		Primary productivity or chlorophyll	*no data*	*no data*	*no data*
		Biodiversity (fish, mammals, etc.)	WFD Report (2016)	Macroalgae status in coastal water bodies	https://www.eea.europa.eu/data-and-maps/data/wise-wfd-4/wise-wfd-database-1/wise-wfd-database
	Coastal marsh	Habitat area	WCMC	Global distribution of Saltmarshes	https://data.unep-wcmc.org/datasets/43
		Importance for Life-history stages of species (i.e. migration and habitat of birds)	Ramsar Convention	Location of Ramsar Sites	(France) https://rsis.ramsar.org/ris-search/?f%5B0%5D=regionCountry_en_ss%3AEurope&f%5B1%5D=regionCountry_en_ss%3AFrance (Spain) https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/ramsar_descargas.aspx
		Vegetation coverage	*no data*	*no data*	*no data*
	Tidal flats and shallow waters	Habitat area	WCMC	Global distribution of Tidal Flat Ecosystems	https://data.unep-wcmc.org/datasets/47

Level	Area	Specific indicators	Sources	Description	Link
		Diversity of benthos	WFD Report (2016)	Status of macroinvertebrates in coastal and transitional water bodies	https://www.eea.europa.eu/data-and-maps/data/wise-wfd-4/wise-wfd-database-1/wise-wfd-database
		Importance for Life-history stages of species (i.e. migration and habitat of birds)	Ramsar Convention	Location of Ramsar Sites	(France) https://rsis.ramsar.org/ris-search/?f%5B0%5D=regionCountry_en_ss%3AEurope&f%5B1%5D=regionCountry_en_ss%3AFrance (Spain) https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/ramsar_descargas.aspx
	Estuary	Primary productivity or Chlorophyll	WFD Report (2016)	Status of phytoplankton in transitional water bodies	https://www.eea.europa.eu/data-and-maps/data/wise-wfd-4/wise-wfd-database-1/wise-wfd-database
		Diversity (swimming species)	WFD Report (2016)	Status of fish in transitional water bodies	https://www.eea.europa.eu/data-and-maps/data/wise-wfd-4/wise-wfd-database-1/wise-wfd-database
		Importance for Life-history stages of species (mainly migration and inhabitation for birds, spawning and migration for fish)	Ramsar Convention	Location of Ramsar Sites	(France) https://rsis.ramsar.org/ris-search/?f%5B0%5D=regionCountry_en_ss%3AEurope&f%5B1%5D=regionCountry_en_ss%3AFrance (Spain) https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/ramsar_descargas.aspx
		Added: location of transitional water bodies	WISE-WFD spatial datasets	Location of transitional water bodies	https://www.eea.europa.eu/data-and-maps/data/wise-wfd-spatial-3
	Island	Importance for Life-history stages of species (mainly for the migration and habitat of birds)	*no data*	*no data*	*no data*
		Diversity (mainly for species only occur on the island and fishery resources in adjacent area)	*no data*	*no data*	*no data*
		Vegetation coverage	*no data*	*no data*	*no data*
		Importance of rights	*no data*	*no data*	*no data*
	Fishery growing area	Importance for Life-history stages of species (fishery resources)	AZTI data	Eggs abundance for five commercial species	AZTI data. Available upon request
		Population importance	*no data*	*no data*	*no data*
	Other unique habitats	Unique	OSPAR (2015)	Threatened and/or declining habitats in the NE Atlantic	https://odims.ospar.org/en/submissions/ospar_habitats_polygons_2015_01/
		Diversity	*no data*	*no data*	*no data*

Table 2. Species of interest in the case study vs. Spatial data availability and Source. The list of species of interest was defined considering the 'OSPAR list of Threatened and/or Declining species' and the 'Reference List for the Marine Atlantic Region' of the Habitats Directive

Species of interest	Spatial data availability (Source)
INVERTEBRATES	
Nucella lapillus	*Not available*
FISH	
Acipenser sturio	Available (IUCN Red List)
Alosa alosa	Available (IUCN Red List)
Alosa fallax	Available (IUCN Red List)
Anguilla anguilla	Available (IUCN Red List)
Centroscymnus coelolepis	Available (IUCN Red List)
Centrophorus granulosus	Available (IUCN Red List)
Centrophorus squamosus	Available (IUCN Red List)
Cetorhinus maximus	Available (IUCN Red List)
Dipturus batis OR Raja batis	Available (IUCN Red List)
Raja montagui OR Dipturus montagui	Available (IUCN Red List)
Hippocampus guttulatus OR Hippocampus ramulosus	Available (IUCN Red List)
Hippocampus hippocampus	Available (IUCN Red List)
Lamna nasus	Available (IUCN Red List)
Lampreta fluviatilis	Available (IUCN Red List)
Petromyzon marinus	Available (IUCN Red List)
Raja clavata	Available (IUCN Red List)
Rostroraja alba	Available (IUCN Red List)
Salmo salar	*Not available*
Squalus acanthias	Available (IUCN Red List)
Squatina squatina	Available (IUCN Red List)
REPTILES	
Caretta caretta	Available (IUCN Red List)
Dermochelys coriacea	Available (IUCN Red List)
MAMMALS	
Balaenoptera musculus	Available (IUCN Red List)
Eubalaena glacialis	Available (IUCN Red List)
Tursiops truncatus	Available (IUCN Red List)
Phocoena phocoena	Available (IUCN Red List)
Halichoerus grypus	Available (IUCN Red List)
Phoca vitulina	Available (IUCN Red List)
BIRDS	
Puffinus mauretanicus	Available (Birdlife)
Sterna dougallii	Available (Birdlife)
Uria aalge	Available (Birdlife)
Hydrobates pelagicus	Available (Birdlife)

The MRECC method requires the available numeric information (i.e., number of species of interest per 1km^2 grid cell) to be transformed to discrete values (areas of High, Medium or Low importance). In this case, expert knowledge was used to discretize species values. As the distribution maps from the IUCN Red List are, at least for some species, poorly detailed (i.e., use of global distribution maps to establish the current occurrence of threatened species within the study site), a very restrictive approach was adopted to classify grid cells into "Mid" or "High" importance areas (Table 3).

Table 3. Adaptation and integration of the specific indicator for species of interest.

MEP: Marine Ecological Protection. Specific Indicator 1: Number of species of interest per grid cell	MEP Method: Integrated indicator
>21	High
19-21	Mid
<19	Low

At the **habitat level**, from the eight types of habitats included in the method (namely Seagrass bed, Seaweed habitat, Coastal marsh, Tidal flats and shallow waters, Estuary, Island, Fishery growing area, Other unique habitats), a total of seven were included in the case study analysis. The "island" category was removed due to the low representativity in the area. The status of each habitat was assessed according to data on specific indicators. The MEP method requires that datasets on specific indicators are aggregated into a single value per habitat type in each grid cell, independently of the number of specific indicators for each habitat type. The process followed in the Bay of Biscay is explained in more detail below.

For **seagrass beds**, the MEP method includes a single specific indicator, "Habitat area and coverage" (Table 1). Based on expert knowledge, the seagrass extent data layer available from the EMODnet Seabed Habitats data portal[11] was not considered complete enough for the study area. Therefore, it was decided to use the angiosperm status in coastal waters from the WFD 2016 Report, as a proxy of seagrass distribution[12]. The WFD classifies the angiosperm ecological status per coastal water body and according to five categories: High, Good, Moderate, Poor, and Bad. In addition, when the status cannot be assessed, the database contains information on Unknown, Unpopulated or No data. This information was transformed into three categories: "High", when angiosperm ecological status was High or Good (i.e., achieving the WFD objectives about the ecological status); "Mid", when angiosperm status was moderate; and "Low", when angiosperm status was any of the other categories, including those for which no data exist. This way, each cell in the case study grid was classified in one of those three categories for the seagrass beds habitat type (Table 4).

Table 4. Adaptation and integration of the specific indicator for seagrass beds. MEP: Marine Ecological Protection; WFD: Water Framework Directive.

Specific Indicator 1: Angiosperm status (WFD Report, 2016)	MEP Method: Integrated indicator
High or Good	High
Moderate	Mid
Bad, Poor, Unknown, Unpopulated, No data	Low

The MEP method includes three specific indicators for **seaweed habitats:** "habitat area", "primary productivity or chlorophyll" and "biodiversity" (Table 1). For the first indicator "habitat area", we considered using the macroalgal canopy extent data layer available in EMODnet Seabed Habitats data portal[13], which is based on available survey data. However, the research team decided not to use this

[11] https://www.emodnet-seabedhabitats.eu/access-data/download-data/ (Access: 18/02/2021)
[12] https://www.eea.europa.eu/data-and-maps/data/wise-wfd-4/wise-wfd-database-1/wise-wfd-database (Access: 19/02/2021)
[13] https://www.emodnet-seabedhabitats.eu/access-data/download-data/?linkid=eov_macroalgae (Access: 18/02/2021)

information and use instead the proxy "infralittoral rocks", extracted from 'EUSeaMap 2019' EMODnet broad-scale seabed habitat map[14], since the information available is more complete and infralittoral rocks are mostly covered by macroalgae in the area. Hence, we assume that the infralittoral rocks cover the same area as 'seaweed habitats'. The second specific indicator for seaweed habitats is "primary productivity or chlorophyll", which was discarded due to the lack of information in the case study. The third and last indicator was "biodiversity". In this case, macroalgae status, as reported for the WFD[15] was used as a proxy. The approach to transform the WFD status (High, Good, Moderate, Poor, Bad) into three categories (High, Mid, Low) was the same as explained for seagrasses, and the two specific indicators for this habitat type were integrated as explained in Table 5.

Table 5. Adaptation and integration of the specific indicators for seaweed habitats. MEP: Marine Ecological Protection; WFD: Water Framework Directive.

Specific Indicator 1: Infralittoral rocks (EMODnet Seabed Habitats)	Specific Indicator 2: Macroalgae status (WFD Report, 2016)	MEP Method: Integrated indicator
Presence	High or Good	High
	Moderate	Mid
	Bad, Poor, Unknown, Unpopulated, No data	Low
Absence	*Any*	Not applicable

The third habitat type considered is **coastal marshes**. The analysis is based on three specific indicators (Table 1): "habitat area", "importance for life-history stages" and "vegetation coverage". To adapt the three indicators to the Bay of Biscay case study, two sources of information have been used. Firstly, the global distribution of saltmarshes, downloaded from the UNEP-WCMC[16] Ocean Viewer portal, has been used as a proxy of "habitat area" indicator. Secondly, the areas included as Ramsar sites (designated according to the Ramsar Convention or Convention on Wetlands)[17] have been used as a proxy for the importance for life-history stages. Finally, the two specific indicators for coastal marshes were aggregated into a single value per grid cell as described in Table 6.

[14] https://www.emodnet-seabedhabitats.eu/access-data/download-data/?linkid=eusm_2019_atlantoarctic (Access: 15/02/2021)
[15] https://www.eea.europa.eu/data-and-maps/data/wise-wfd-4/wise-wfd-database-1/wise-wfd-database (Access: 19/02/2021)
[16] https://data.unep-wcmc.org/datasets/43 (Access: 19/02/2021)
[17] Spain: https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/ramsar_descargas.aspx (Access: 22/10/2021)
France: https://rsis.ramsar.org/ris-search/?f%5B0%5D=regionCountry_en_ss%3AEurope&f%5B1%5D=regionCountry_en_ss%3AFrance

Table 6. Adaptation and integration of the specific indicators for coastal marshes. MEP: Marine Ecological Protection; UNEP-WCMC: United Nations Environment Programme-World Conservation Monitoring Centre.

Specific Indicator 1: Global distribution of saltmarshes (UNEP-WCMC)	Specific Indicator 2: Ramsar sites designation[16]	MEP Method: Integrated indicator
Presence	Yes	High
	No	Mid
Absence	*Any*	Not applicable

The fourth habitat type in the MEP method is **tidal flats and shallow waters**, which are analysed according to three specific indicators: "habitat area", "diversity of benthos" and "importance for life-history stages". The specific indicator "habitat area" has been adapted to the case study using the data layer "Global distribution of tidal flats", retrieved from UNEP-WCMC[18]. For "diversity of benthos", the ecological status of macroinvertebrates reported under the WFD in 2016, both in coastal and transitional waters[19]. Finally, for "importance for life-history stages", the designated Ramsar sites have been used[16] (i.e., 'Yes' are the areas with designated sites, and 'No' without sites). The three indicators were aggregated into a single value for tidal flats and shallow waters' importance, as described in Table 7.

Table 7. Adaptation and integration of the specific indicators for tidal flats and shallow waters. MEP: Marine Ecological Protection; UNEP-WCMC: United Nations Environment Programme-World Conservation Monitoring Centre; WFD: Water Framework Directive

Specific Indicator 1: Global distribution of tidal flats (UNEP-WCMC)	Specific Indicator 2: Ramsar sites designation[16]	Specific Indicator 3: Status of macroinvertebrates (WFD Report, 2016)	MEP method: Integrated indicator
Presence	Yes	*Any*	High
	No	High, Good	High
		Moderate	Mid
		Poor, Bad, Unknown, Unpopulated, No data	Low
Absence	*Any*	*Any*	Not applicable

Estuarine habitats are characterized according to three specific indicators: "primary productivity or chlorophyll", "diversity of swimming species", and "importance for life-history stages" (Table 1). The method has been adapted to the case study by aggregating four sources of information. First, for the location of these habitats, the "transitional water bodies" location, as included in the WISE WFD reference spatial data sets[20], has been used. As proxies of the specific indicators "primary productivity or chlorophyll" and "diversity of swimming species", the ecological status of phytoplankton and the

[18] https://data.unep-wcmc.org/datasets/47 (Access: 22/10/2021)
[19] https://www.eea.europa.eu/data-and-maps/data/wise-wfd-4/wise-wfd-database-1/wise-wfd-database (Access: 19/02/2021)
[20] https://www.eea.europa.eu/data-and-maps/data/wise-wfd-spatial-3 (Access: 19/02/2021)

ecological status of fish in transitional waters, reported under the WFD, have been used, respectively[21]. Finally, for the "importance for life-history stages" indicator, the location of designated Ramsar sites have been used[16], as explained above for tidal flats. The aggregation of the information to achieve a single category per cell was done as described in Table 8. Within the same grid cell, the ecological status of phytoplankton and the ecological status of fish could be different. In those cases, a precautionary approach was adopted to aggregate the indicators by taking the highest of the two values as the value for the cell.

Table 8. Adaptation and integration of the specific indicators for estuaries. MEP: Marine Ecological Protection; WFD: Water Framework Directive; WISE: Water Information System for Europe.

Specific Indicator 1: Location of transitional water bodies (WISE-WFD)	Specific Indicator 2: Status of phytoplankton (WFD Report, 2016)	Specific Indicator 3: Status of fish (WFD Report, 2016)	Specific Indicator 4: Ramsar sites[16]	MEP Method: Integrated indicator
Presence	*Any*	*Any*	Yes	High
	High, Good		No	High
	Moderate		No	Mid
	Bad, Poor, unpopulated, Unknown		No	Low
Absence	*Any*	*Any*	*Any*	Not applicable

Information of five commercial fish species has been used to assess the **fishery growing areas** in the case study. More precisely, egg data for anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*), hake (*Merluccius merluccius*), Atlantic horse mackerel (*Trachurus trachurus*) and Atlantic mackerel (*Scomber scombrus*) were gathered. These species were selected because four of them ranked in the Top 5 in terms of live weight of landings in the Bay of Biscay (>40% of the total in 2016 and 2017[22]), and in the Top 10 in terms of value of landings (30% of the total in 2016 and 2017[23]). The historical data of egg distribution and abundance (egg km^{-2}), for the five species, was used to spatially delimit the spawning grounds. The data available per species are: (i) for anchovy, yearly data from 1989 to 2020 (32 campaigns); (ii) for sardine, yearly data from 1998 to 2020 (23 campaigns); (iii) for hake, data every three years, from 1995 to 2016 (8 campaigns); and (iv) for Atlantic horse mackerel and Atlantic mackerel, data every three years, from 1992 to 2019 (10 campaigns).

To transform the original point data into a single layer covering the whole case study area, a geostatistical interpolation was performed in QGIS version 3.16.11-Hannover (QGis.org, 2022) using the Ordinary Kriging technique. The data were split by species and year, obtaining between 32 and 8

[21] https://www.eea.europa.eu/data-and-maps/data/wise-wfd-4/wise-wfd-database-1/wise-wfd-database (Access: 19/02/2021)

[22] Aggregated values were estimated with reported landings in 2016 and 2017 in the sub-regions 27.8.a, 27.8.b, 27.8.c and 27.8.d (STEFC Report 2019: https://stecf.jrc.ec.europa.eu/reports/economic/-/asset_publisher/d7Ie/document/id/2571760?inheritRedirect=false&redirect=https%3A%2F%2Fstecf.jrc.ec.europa.eu%2Freports%2Feconomic%3Fp_p_id%3D101_INSTANCE_d7Ie%26p_p_lifecycle%3D0%26p_p_state%3Dnormal%26p_).

[23] Aggregated values were estimated with value of landings in 2016 and 2017 in the sub-regions 27.8.a, 27.8.b, 27.8.c and 27.8.d (STEFC Report 2019: https://stecf.jrc.ec.europa.eu/reports/economic/-/asset_publisher/d7Ie/document/id/2571760?inheritRedirect=false&redirect=https%3A%2F%2Fstecf.jrc.ec.europa.eu%2Freports%2Feconomic%3Fp_p_id%3D101_INSTANCE_d7Ie%26p_p_lifecycle%3D0%26p_p_state%3Dnormal%26p_).

raster layers per species. For each raster file, the pixel values were then aggregated to fit the case study grid using the zonal statistics tool in QGIS. Using these layers, the mean value per grid cell was estimated for each species. This value was then used to discretise data, following the work done previously to detect areas of high-density of marine organisms (Cañadas and Vázquez, 2014; García-Baron et al., 2019): the mean abundance (egg km^{-2}) was ordered from highest to lowest values. The cells with the highest abundance values and comprising a cumulative abundance of 30%, were considered as "presence" (i.e., "High") abundance cells, while the rest of the cells were considered as "absence" (i.e., "Low") importance cells. The threshold of 30% was chosen after exploring the options of 40%, 30%, 20% of cumulative abundance of eggs, and after consultation with AZTI experts, the choice of the 30% was selected as is the one that includes most of the important areas for spawning of the five species, without being too large for a feasible protection and cost-effective monitoring.

For the last category of habitats level, the **Other unique habitats** type, the "OSPAR threatened and/or declining habitats in the northeast Atlantic" data layer has been used[24]. A total of three types of threatened and/or declining habitats can be found in the area: Deep-sea sponge aggregations, *Lophelia pertusa* reefs and *Zostera* spp. beds. To avoid double-counting with the information already collected for "seagrass habitats", *Zostera* beds were removed from the data base. Therefore, the other two habitats were included in "Other unique habitats". The aggregation was done using a simple rule: if any of the two habitats was present in the cell, the cell was classified as "High", and as "Low" otherwise.

Finally, the **genes level** could not be assessed due to the lack of accessible information for the case study, despite recent advances in this topic in the area (Fraija-Fernández et al., 2020).

2.2.1.2 Importance of coastal protection function

The MEP method assesses the importance of the coastal protection function by identifying biological and physical protection areas. Regarding the biological protection, the method considers that areas with habitats such as saltmarshes or coastal forests with high patch density, large vegetation coverage and/or covering wide areas are of high importance for their capacity to provide biological protection. Regarding the physical protection, the MEP method classifies as low or high importance depending on whether the coastline is predominantly characterized by bedrock or sandy shores. In case of rocky coasts, if this is of large scale and un-interrupted (>1 km), the area is considered of high importance for the physical protection function; for sandy shores, the method considers that areas with gentle slope, of large scale and un-interrupted and quite flat are the ones with high importance.

In the Bay of Biscay, instead of developing a new metric for the coastal protection function it was decided to use the Coastal Protection Capacity (CP_{cap}) indicator, designed by Liquete *et al.* (2013). This indicator is described as "*the natural potential that coastal ecosystems possess to protect the coast against inundation or erosion, based on geological and ecological characteristics*". The indicator, which requires input variables such as slope, geomorphology, submarine habitats and emerged habitats, has already been estimated for the whole European coast and the data are available on request. Based on the indicator description and the variables considered in its estimation, it was considered as a good proxy for the coastal protection function of the MRECC method.

Liquete *et al.* (2013) calculated the CP_{cap} indicator for the coastal zone (i.e., the area potentially affected by extreme hydrodynamic conditions), and delimited it by the 50 m depth isobath and the 50 m height contour line. The CP_{cap} values were normalized from 0 to 1 and presented as irregular

[24] https://odims.ospar.org/en/maps/map-threatened-or-declining-habitats/ (Access: 16/07/2021)

polygons in the data layer. To include CP_{cap} values to the case study grid and to the MRECC method, firstly, for each grid cell the CP_{cap} was re-calculated as the mean of all the values contained within the cell. Secondly, considering the range and distribution of CP_{cap} values the 33rd and 67th (1/3 and 2/3) percentiles were used to discretize them in a three-category indicator: “High Importance”, “Mid Importance” and “Low Importance”.

2.2.1.3 Assessment of coastal vulnerability

In the MEP method, the assessment of coastal vulnerability is done considering coastal erosion and sand loss. Coastal erosion and sand loss are assessed using parameters such as coastal sediment types, storm surge and erosion rate, as well as identification of vulnerable natural coast and restored sandy/silty/muddy coasts. Area is defined by geographic boundary from shoreline to land (Annex 1: Technical guidance on evaluation of Marine Resource-Environment Carrying Capacity and Spatial Development Suitability (official version).

For this assessment, the team decided to use the Coastal Protection Exposure (CP_{exp}) indicator, designed by Liquete *et al.* (2013). This indicator is described as *“The predicted need of coastal protection based on the climatic and oceanographic conditions of each area”.* The indicator integrates information on wave regime, tidal range, relative sea level and storm surge. As for CP_{exp} has also been estimated for the whole European ‘coastal zone’ and the data are available on request.

High values of CP_{exp} correspond with a highly vulnerable area (i.e., ‘very vulnerable’ following the MEP method and the coastal vulnerability assessment) and were classified as ‘High’ in the Bay of Biscay case study; while low CP_{exp} values correspond with less vulnerable areas (i.e., ‘average’ following the MEP method and the coastal vulnerability assessment) and are classified as ‘Low’ in the case study. Intermediate values were classified as ‘Mid’. The adaptation of CP_{exp} numeric values to the case study grid and the assessment of the coastal vulnerability for the MEP method, which requires character values, was done as for CP_{cap} adaptation to coastal protection function (see section 2.2.1.2).

2.2.2 Current marine development and utilization

Chinese methodology evaluates the suitability for marine spatial development of a few human activities (e.g., port construction, oil and gas development, marine aquaculture, offshore wind farm) (see Annex 1: Technical guidance on evaluation of Marine Resource-Environment Carrying Capacity and Spatial Development Suitability (official version). However, data for suitable marine spatial development in these activities are not adequate for the study area. Hence, we decided to study the current marine development and utilization, selecting a total of nine human activities, which represent the main activities in the area. Each of them was individually assessed, intersecting the information on the utilization of marine environment (current or, when available, prospective), with the MEP areas. When an activity takes place in a cell, the area was considered as of ‘High Importance’ for the activity, irrespective of the intensity, excepting the cases of tourism and recreation, fisheries, and shipping. For these three activities, the available data allow classifying the importance of the area according to the intensity of the activity (i.e., High. Mid, Low).

2.2.2.1 Marine protected areas

To delimit the marine protected areas (MPAs) in the case study, three sources of information were used: OSPAR protected areas[25], Natura 2000 areas[26] and Nationally Designated areas[27].

The protected areas were transferred to the grid solving possible overlaps. The cells where any of the protection figure abovementioned was present were classified as "High" importance areas, while the rest were classified as "not present".

2.2.2.2 Marine aquaculture

To characterize the marine aquaculture activity, the current location of marine aquaculture facilities for marine fish[28], shellfish[29] and algae[30], from EMODnet Human Activities was used. The cells where any marine aquaculture activity was present were classified as "High" importance areas, while the rest were classified as "not present".

2.2.2.3 Ports

Information on the location of main ports within the case study was obtained from the Word Port Index of the Maritime Safety Information web[31]. This webpage includes spatial location of the main ports of the world. The cells where a port was located were classified as "High" importance areas, while the rest were classified as "not present".

2.2.2.4 Operational and future ocean energy production facilities: wind power, wave and tidal energy

Location of wind farms[32] and ocean energy tests sites[33] facilities were obtained from EMODnet Human Activities. The cells where any of these facilities was present were classified as "High" importance areas, while the rest were classified as "not present".

2.2.2.5 Aggregate extraction and dredging

The location of aggregate extraction areas and dredging activities were obtained from EMODnet Human Activities[34,35]. The aggregate extraction database includes active and non-active extraction areas, in polygon format. Within the case study area, this activity is only allowed in France. The

[25] https://carto.mpa.ospar.org/fr/1/ospar.map (Access: 05/03/2021)
[26] https://www.eea.europa.eu/data-and-maps/data/natura-11 (Access: 24/02/2021)
[27] https://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-15 (Access: 05/03/2021)
[28] https://www.emodnet-humanactivities.eu/search-results.php?dataname=Finfish+Production (Access: 04/03/2021)
[29] https://www.emodnet-humanactivities.eu/search-results.php?dataname=Shellfish+Production (Access: 04/03/2021)
[30] https://www.emodnet-humanactivities.eu/search.php (Access: 04/03/2021)
[31] https://msi.nga.mil/Publications/WPI (Access: 04/03/2021)
[32] https://www.emodnet-humanactivities.eu/search-results.php?dataname=Wind+Farms+%28Polygons%29 (Access: 04/03/2021)
[33] https://www.emodnet-humanactivities.eu/search-results.php?dataname=Test+Sites (Access: 04/03/2021)
[34] https://www.emodnet-humanactivities.eu/search-results.php?dataname=Aggregate+Extraction+Areas
[35] https://www.emodnet-humanactivities.eu/search-results.php?dataname=Dredging (Access 04/03/2021)

dredging activities database includes points where dredging operations have occurred, including dredged sediment disposal in coastal areas.

For the two activities, the cells where the activity is present, were classified as "High" importance areas, while the rest were classified as "not present".

2.2.2.6 Fisheries

To characterise the fishing activity, 'fishing intensity' extracted from EMODnet Human activities[36] was used. More precisely, the average annual fishing effort (mW fishing hours) per gear type were used. In the Bay of Biscay, these values were estimated with 2018-2021 VMS/logbook data. The original data were presented aggregated in a 0.05x0.05 degrees grid per gear type (beam trawls, bottom otter trawls, bottom seines, dredges, pelagic trawls and seines, and static gears). To adapt these data to the MRECC method, first, the summatory of all gear types was estimated per case study grid cell (1 x 1 km^2). Next, the numeric values were transformed into categorical values using 70% and 90% quantiles: <0.7 as 'Low', 0.7-0.9 as 'Mid', and >0.9 as 'High'.

2.2.2.7 Military areas

The location of military areas was obtained from EMODnet Human Activities[37]. Military areas are usually defined as exclusion areas for other human activities. Therefore, it was considered interesting to include them in the analysis. Unfortunately, within the case study area, only information for Spain was available.

To codify the activity in categorical format, the cells where the activity was present were classified as "High" importance areas, while the rest were classified as "not present".

2.2.2.8 Tourism and recreation

Two indicators were used to characterise the tourism and recreation activities: (i) location of bathing waters[38], as reported by Member States to the EEA (Reference year: 2019) and (ii) vessel density of different type of recreational vessels[39,40] available from the EMODnet Human Activities portal.

The cells where bathing waters were present were classified as "High" importance areas, while the rest were classified as "not present".

For vessel density, the subtypes 'Sailing' and 'Pleasure Crafts' were considered (monthly average measured in 'hours per km^2 per month'). Although information is available for 2017-2020 years, we decided to download 2019 data, as the outbreak of the COVID-19 pandemic in 2020 could have altered the activity. The original information is in raster format and was transferred to the case study grid using the zonal statistics tool in QGIS (QGis.org, 2022). With this tool, the mean value for each vessel

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[36] https://www.emodnet-humanactivities.eu/search-results.php?dataname=Fishing+Intensity (Access 23/03/2022)

[37] https://www.emodnet-humanactivities.eu/search- results.php?dataname=Military+Areas+%28Polygons%29 (Access: 04/03/2021)

[38] https://www.eea.europa.eu/data-and-maps/data/bathing-water-directive-status-of-bathing-water-12 (Access: 04/03/2021)

[39] Route density: https://www.emodnet-humanactivities.eu/search-results.php?dataname=Route+density+%28source%3A+EMSA%29 (Access: 05/03/2021)

[40] Vessel density https://www.emodnet-humanactivities.eu/search-results.php?dataname=Vessel+Density+ (Access: 01/07/2021)

subtype and per grid cell was estimated. Then, the vessel density of the two vessel sub-types was summed. In order to adapt this numerical value to the requirements of the MRECC method (categorical value), the 70% and 90% quantiles were used: <0.7 as ‘Low’, 0.7-0.9 as ‘Mid’, and >0.9 as ‘High’.

For each cell, the aggregated value for tourism and recreation activity was estimated as the highest value of the two indicators considered (bathing waters and vessel density).

2.2.2.9 Shipping

Two sources of information were used to characterise the shipping activity: i) vessel density of different types of vessel (monthly average measured in ‘hours per km^2 per month’), and ii) vessel route density of different types of vessel (unit: routes per km^2). Both datasets were downloaded from the EMODnet Human Activities portal.

For vessel density, information on cargo, tanker, passenger, and high-speed crafts was used, while for vessel route density, data on cargo, tanker and passenger vessels were used. The original information, available in raster format, was transformed using the methodology already explained for tourism and recreation (see section 2.2.2.8).

For each cell, the aggregated value for shipping activity was estimated as the highest value of the two indicators considered (vessel density and vessel route).

2.2.3 Data aggregation

2.2.3.1 Aggregation of the marine ecological protection

In order to estimate the MEP value, the importance values of marine biodiversity maintenance areas (species and habitats), coastal vulnerability and coastal protection function values have been considered (Figure 3).

In each cell, the highest value reported for any of the four components is considered as the overall value or the MEP value. Each component has also subcomponents with a different number of indicators, which are all integrated. By giving to all the elements the same weight (or importance) we followed a conservative approach, since having a single component classified as ‘High’ is enough to classify the cell as ‘High’ for its MEP importance.

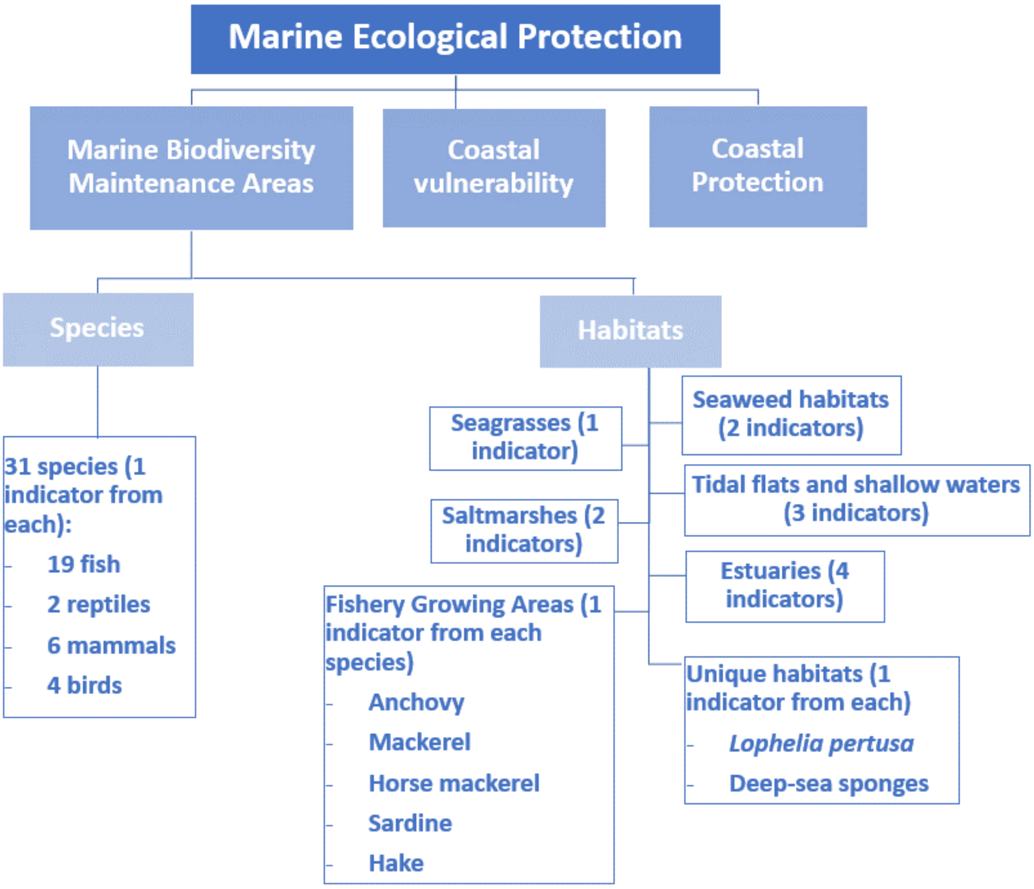

Figure 3. Aggregation of the components to estimate the Marine Ecological Protection value.

2.2.3.2 Aggregation of the current marine development and utilization

In this report, the current marine development and utilization was analysed considering the activities that already occur or are planned in the study area. To obtain a single value of current 'human activity importance' in each cell, all the activities except marine protected areas were aggregated, considering as the overall value the highest importance reported for any of the human activity indicators (Figure 4). Marine protected areas were excluded from the analysis, since they are not activities causing pressures to the marine system, and only those resulting in harm to the ecosystem components have been considered in the aggregation.

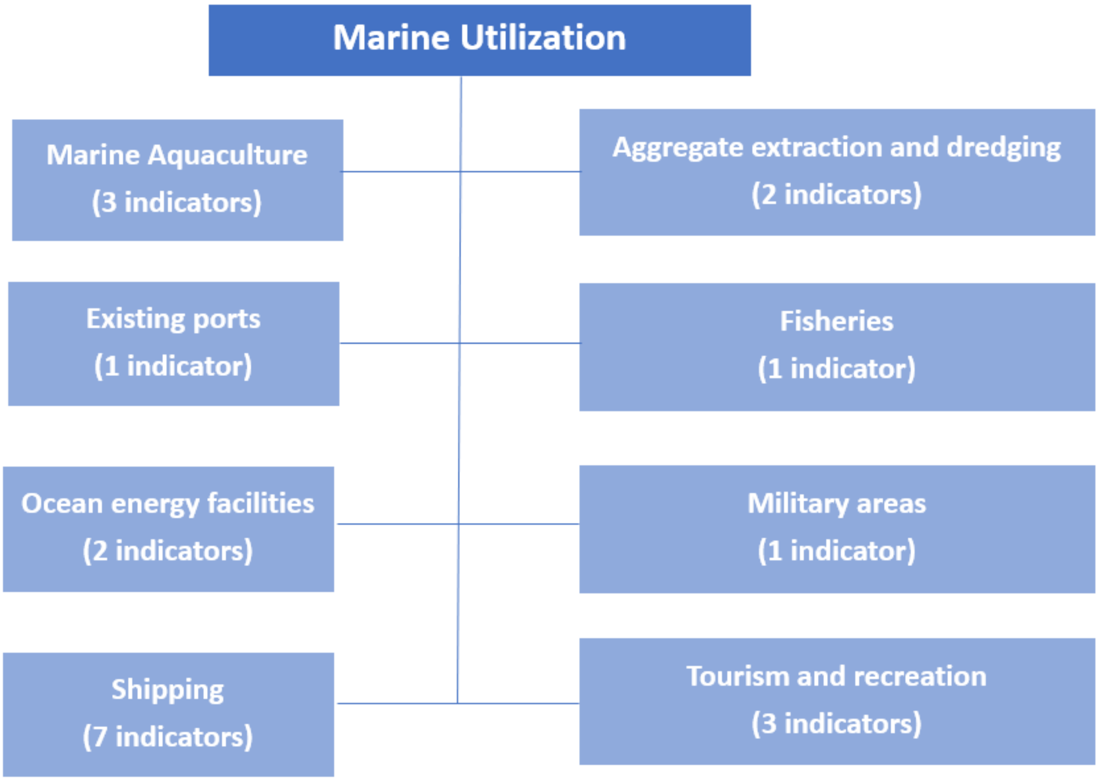

Figure 4. Aggregation of the components to estimate the Current Marine Development and Utilization value.

2.2.3.3 Risk and Environmental Carrying Capacity: Marine Ecological Protection vs. current marine development and utilization

The 'Human activity importance' and 'MEP importance' data products were combined to estimate an indicator of the "Ecological Risk" in the cell. These 'Risk' values were estimated following the rules indicated in Table 9.

Table 9. Importance of Marine Ecological Protection vs. Human activities

		Human activity importance			
		High	Mid	Low	No current use
Marine Ecological Protection importance	High	*High*	*High*	*Mid*	*Low*
	Mid	*Mid*	*Mid*	*Low*	*Low*
	Low	*Low*	*Low*	*Low*	*Low*

2.2.3.4 Marine Ecological Protection vs. fishing activity

Considering that fishing could be one of the most extensive and pervasive human activities at sea, impacting different ecosystem components (Lewinson et al., 2014; Halpern et al., 2019; Pitcher et al., 2022), we intersected the MEP importance with the fishing activity. Two analyses were performed: first, in areas of 'High' MEP, the intensity of fishing activity was estimated with the two indicators: fishing vessel density and fishing vessel route density. Secondly, the areas of high fishing activity intensity were filtered to check the values of MEP within the area.

2.2.3.5 Marine Ecological Protection vs. Marine Protected Areas and estimation of the Marine Resource-Environment Carrying Capacity

The importance of MEP was intersected with the current protection, by analysing the values of MEP within the Marine Protected Areas.

This intersection can provide interesting information on the level of match between already set protected areas and the ecological importance of the areas, calculated in terms of MEP.

Finally, the original methodology was slightly adapted to calculate the MRECC within the study area, estimating it as the area in which neither high importance of MEP nor Marine Protected Areas (i.e., areas not suitable for marine spatial development) exist.

3 Results

3.1 Evaluation of the Marine Ecological Protection

3.1.1 Marine biodiversity maintenance areas

The species included in the lists of interest in the case study grid ranged between 1 and 27 species per km^2. The aggregated importance at species level is presented in Figure 5. In total, 20,115 km^2 were classified as "High importance" (6% of the case study) and 104,502 km^2 as "Mid importance" (29% of the case study) due to their species-level relevance.

There are three main High Importance areas: two in the Spanish continental platform and one in the French continental platform. Other smaller areas of High Importance are located in estuarine and coastal zones (Figure 5). Mid importance areas are in the whole continental platform of the Bay of Biscay, down to the slope, while most of the deep-sea areas have low importance (Figure 5).

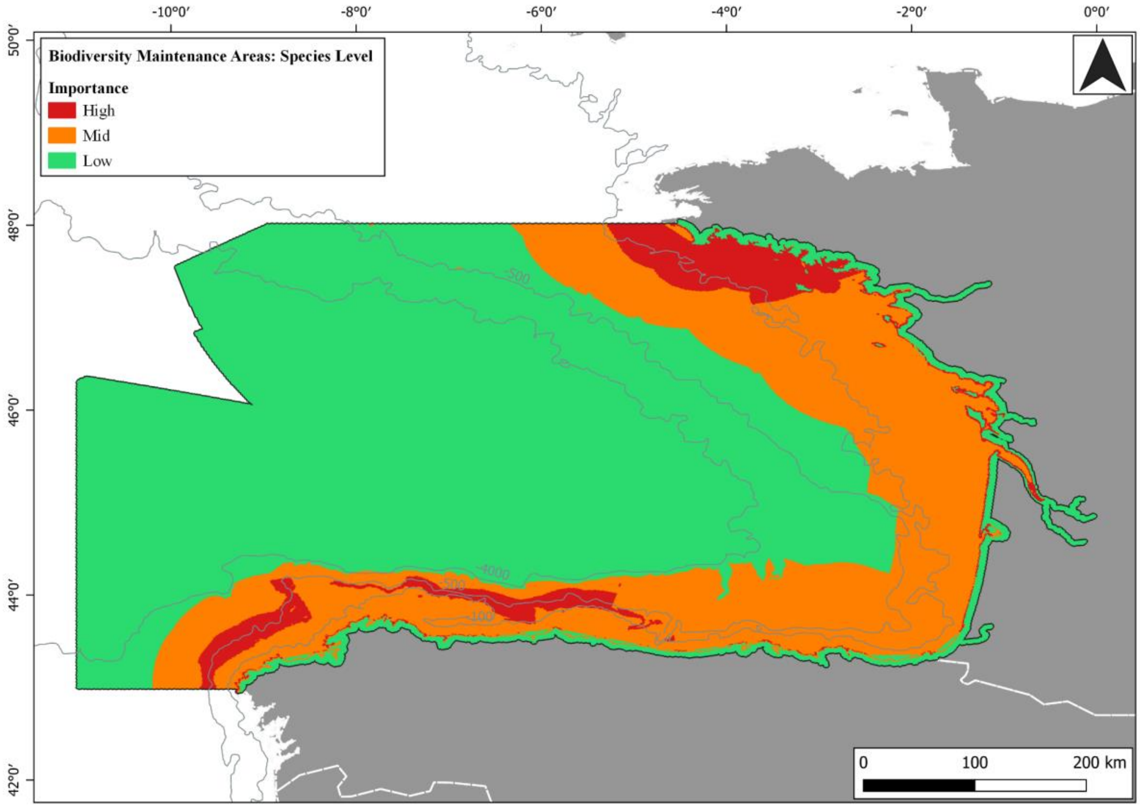

Figure 5. Marine biodiversity maintenance areas: Species level.

The aggregated importance at habitat level is presented in Figure 6. The distribution is sparser than in the case of species, but again most of the High Important areas are located within the continental shelf and estuaries, with small areas in the deep-sea, corresponding to unique habitats and/or fishery growing areas.

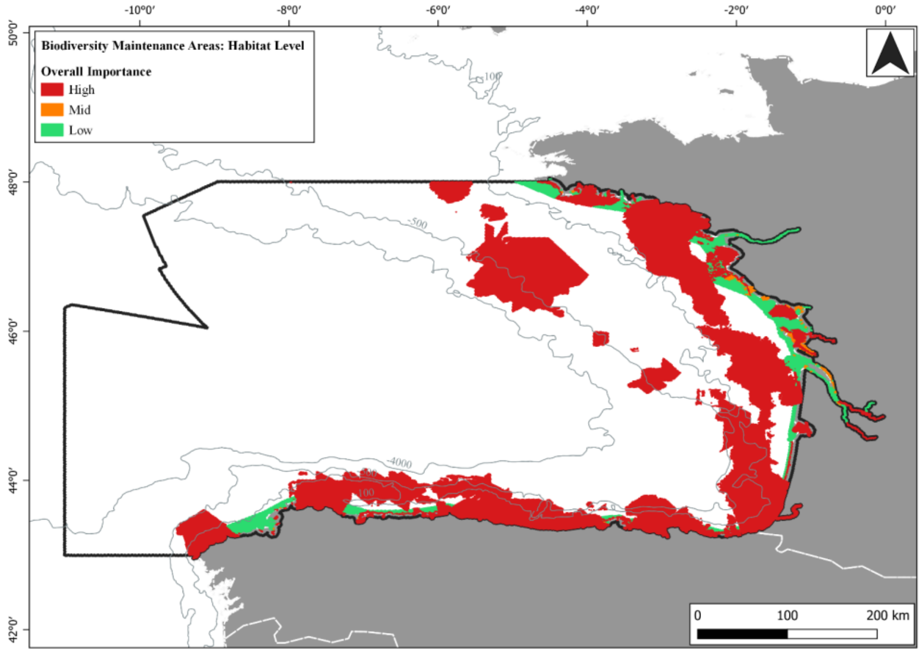

Figure 6. Marine biodiversity maintenance areas: Habitat level.

However, not all areas with high importance have the same number of habitats in high. From the potential seven habitats, up to five habitats of high importance can overlap in the same cell. These 5-habitat cells are in the northern part of the bay, close to the coast (Figure 7). In most cases only one habitat of high importance occurs in a cell. Intermediate values (2-4 overlaps) are close to the coast or in the slope of the continental shelf (Figure 7). In the case of coastal areas, the overlaps come mainly from seaweeds, seagrasses and fishery growing areas, whilst in the slope the overlaps come from fishery growing areas and unique habitats.

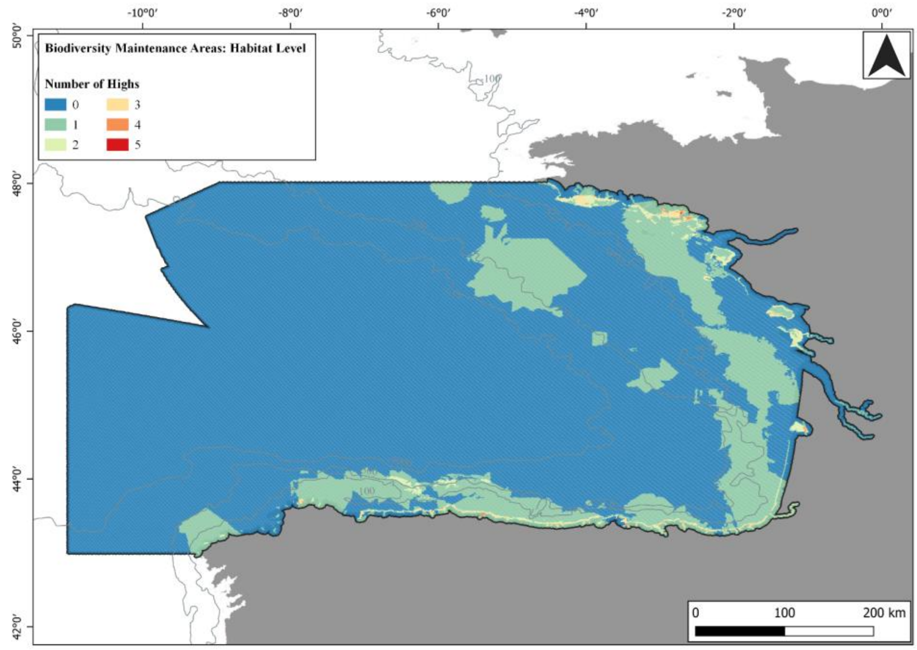

Figure 7. Marine biodiversity maintenance areas: Habitat level. Number of "Highs" per square kilometre.

The importance of each habitat type has been also calculated individually. The area covered by each habitat type, classified by importance level (High, Mid, Low), is summarized in Table 10. The maps of the individual assessments per habitat types are included in 'Annex 3: Individual maps for Habitats'.

Table 10. Importance (High, Mid, Low) (in km^2) of each habitat type and total aggregated habitats value.

Habitat type	Characterized areas (km^2)			Areas not characterized or not relevant for the habitat (km^2)
	High Importance	Mid Importance	Low Importance	
Seagrass beds	2,159	0	12,603	349,876
Seaweed habitats	2,594	431	1,508	360,105
Coastal marshes	341	761	0	365,536
Tidal flats and shallow waters	2,432	10	1,767	360,429
Estuaries	1,437	0	884	362,317
Fishery growing areas:	58,335	0	0	306,303
Engraulis encrasicolus	*13,808*	*0*	*0*	*350,830*
Sardina pilchardus	*12,447*	*0*	*0*	*352,191*
Merluccius merluccius	*9,964*	*0*	*0*	*354,674*
Trachurus trachurus	*13,780*	*0*	*0*	*350,858*
Scomber scombrus	*17,892*	*0*	*0*	*346,746*
Other unique habitats	886	0	0	363,752
Aggregated Habitats Value	62,449	479	6,123	295,587

Of the 364,638 km^2 of the total case study area the most extensive habitat of high importance is fishery growing areas, which covers 16% of the surface. The remainder habitats cover a much smaller area, representing only between 0.2% (other habitats) and 4% (seagrass beds) of the total surface (Table 10).

3.1.2 Importance of coastal protection

The Coastal Protection Capacity indicator, which includes slope, geomorphology, submarine habitats and emerged habitats, describes the natural potential that coastal ecosystems possess to protect the coast against inundation or erosion. The highest values correspond to a narrow strip across the whole northern Spain and most part of the south of France, whilst the northern part was mainly classified as low or mid importance (Figure 8).

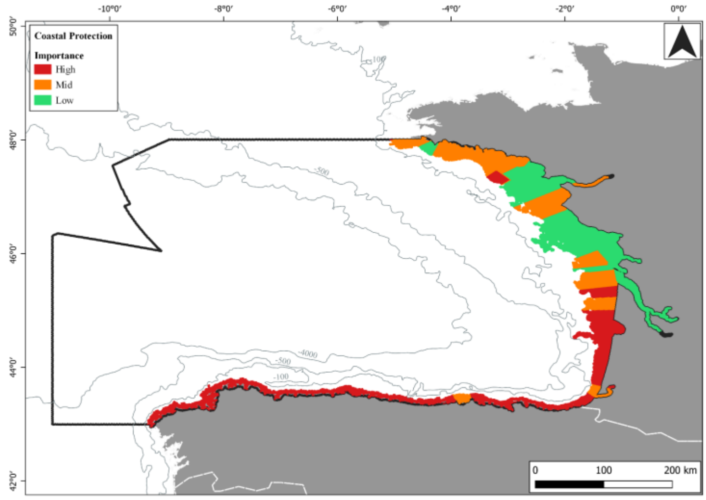

Figure 8. Assessment of the coastal protection function.

3.1.3 Assessment of coastal vulnerability

The coastal vulnerability, which integrates information on wave regime, tidal range, relative sea level and storm surge, is a near mirror image of the previous one, with low coastal vulnerability in northern Spain and south of France, and higher vulnerability values in part of Galicia (west Spain) and the north of France (Figure 9).

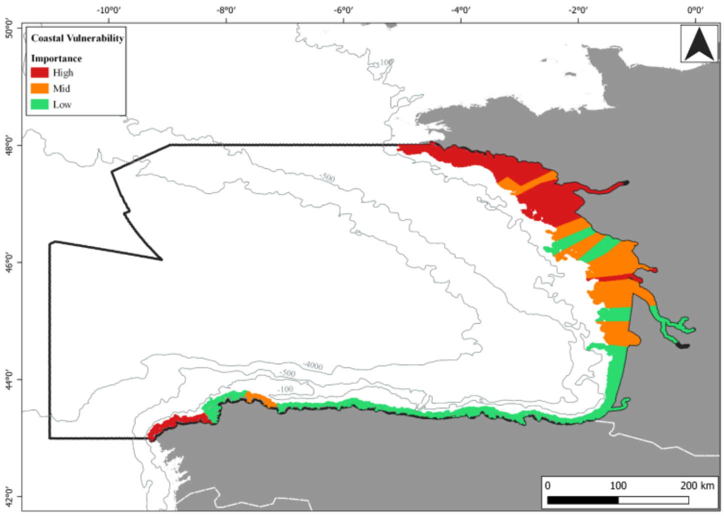

Figure 9. Assessment of the coastal vulnerability.

3.1.4 Aggregated assessment: Marine Ecological Protection

The assessment of the MEP in the Bay of Biscay, which is the result of aggregating marine biodiversity maintenance areas at species and habitat level, coastal protection and coastal vulnerability, is presented in Figure 10. The estuaries, coastal area and continental platform concentrate most of the "High" importance areas, whilst mid importance areas are restricted to the continental platform and part of the deep-sea and low importance areas are mainly offshore.

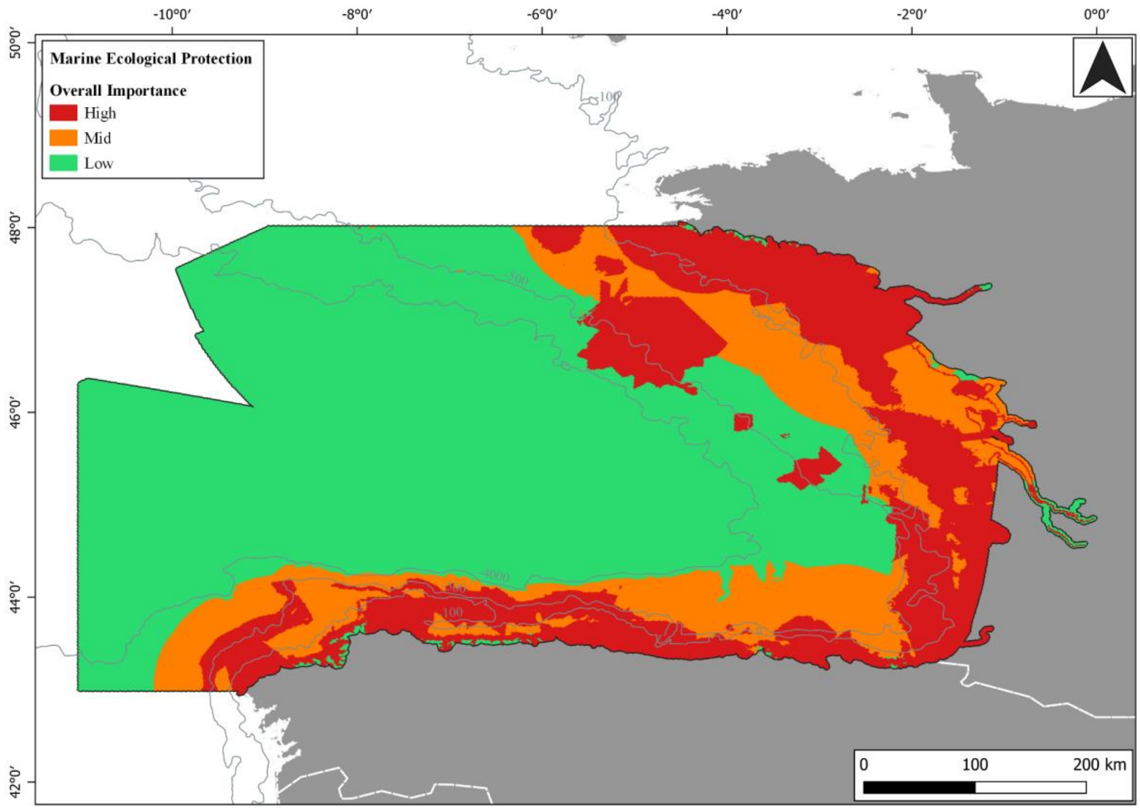

Figure 10. Marine ecological protection in the Bay of Biscay.

A total of 81,759 km^2 (22% of case study) were classified as of High importance for the MEP, 61,838 km^2 as Mid (17%) and 221,041 km^2 as Low (61%). If in a single cell, for any of the four components the cell was classified as High, the cell was considered of High importance for the MEP. Therefore, it can be relevant to know, for the cells classified as High, for how many components the value is High per cell (Figure 11). The case study had between zero and seven components ranked as "High" per km^2, from the ten possible components (one for species, seven for habitats, one for coastal protection and one for coastal vulnerability).

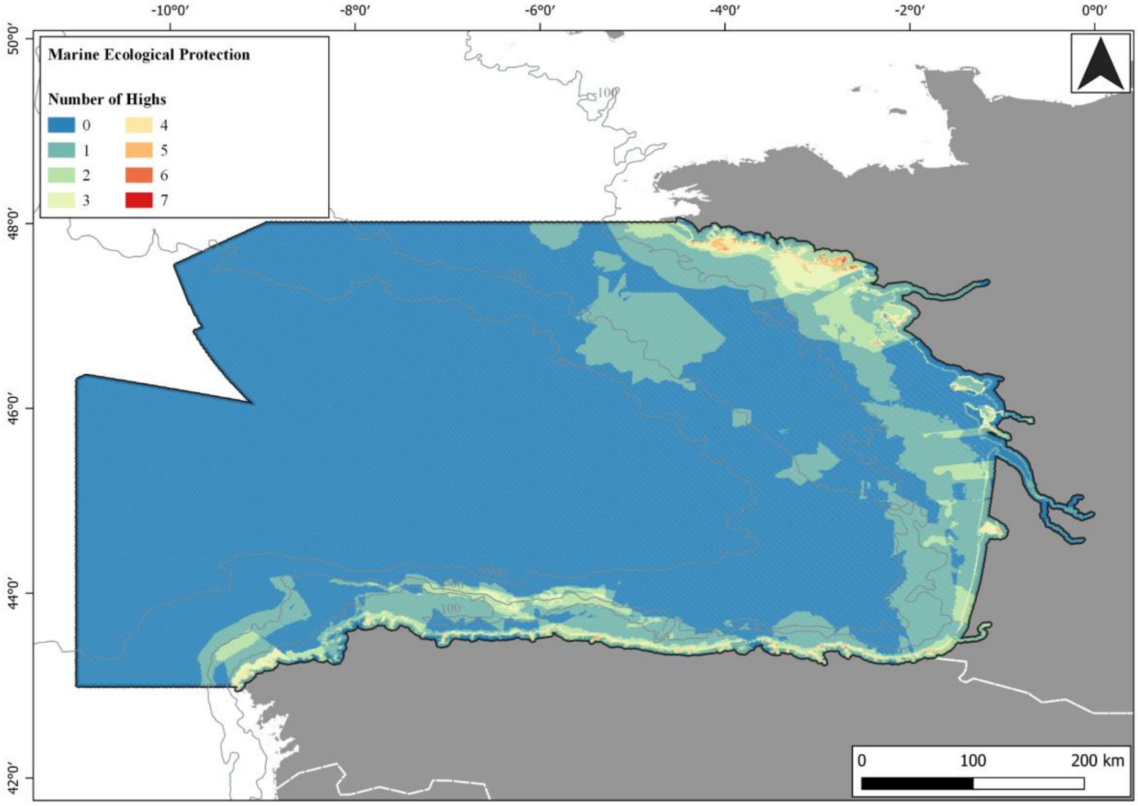

Figure 11. High Importance Marine Ecological Protection (MEP) areas.
Cells ranked according to the number of MEP components for which the cell ranked as "High".

3.2 Current marine development and utilization

3.2.1 Protected areas

After accounting for possible duplicates between Natura2000 sites (Special Protection Areas [SPAs] and Special Areas of Conservation [SACs]), OSPAR Marine Protected Areas and Nationally Designated Areas, a total area of 88,698 km^2 (24%) of the case study was covered with one or various type of marine protected area designation, and therefore, classified as of "High Importance" (Figure 12). Again, most of these areas are coastal, including estuaries, some are located on the slope of the continental shelf, with very few covering deep-sea areas.

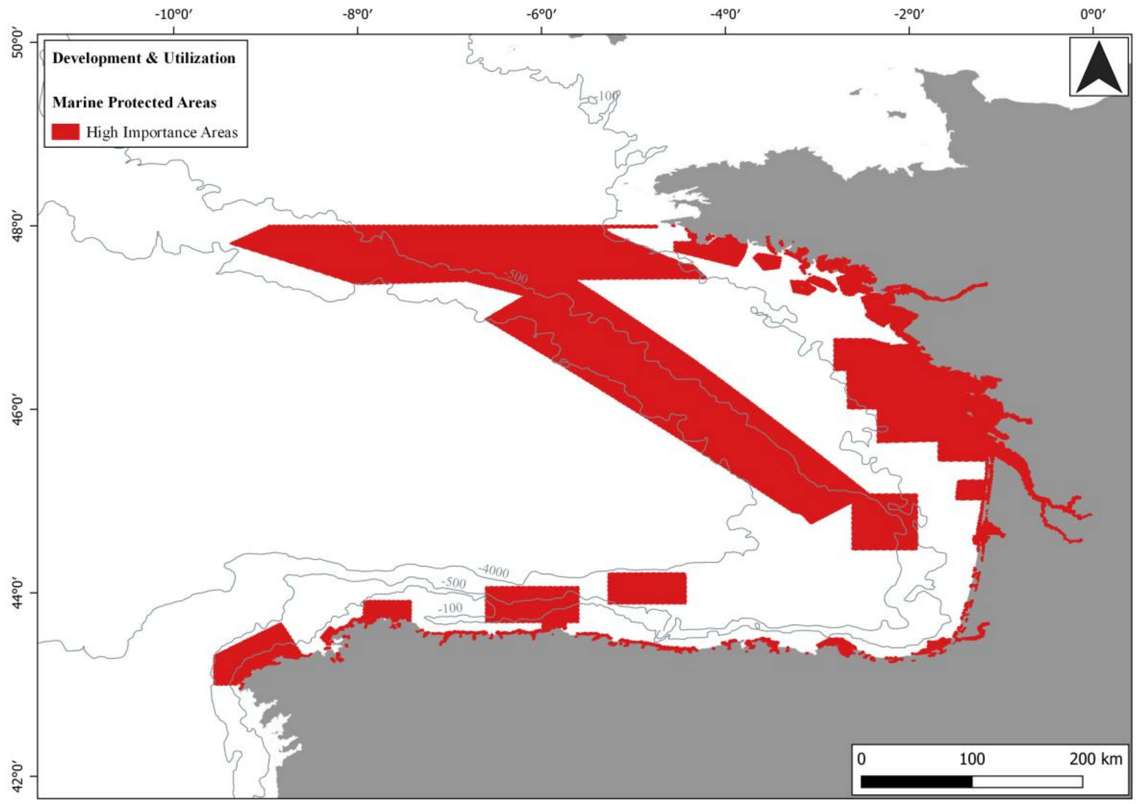

Figure 12. Marine Protected Areas in the Bay of Biscay, including Natura2000 sites, OSPAR Marine Protected Areas and Nationally Designated Areas.

3.2.2 Marine aquaculture

Three types of aquaculture facilities were considered: finfish aquaculture, shellfish aquaculture and algae production (Figure 13).

In the case study, a total of 19 algae production facilities, 119 shellfish aquaculture and eight finfish aquaculture facilities were found, most of them located along the French coast (Figure 13). The original data were point data, and those points were translated to the case study 1x1 km grid directly. However, the total extension of the facilities could be bigger that what it is represented in Figure 13.

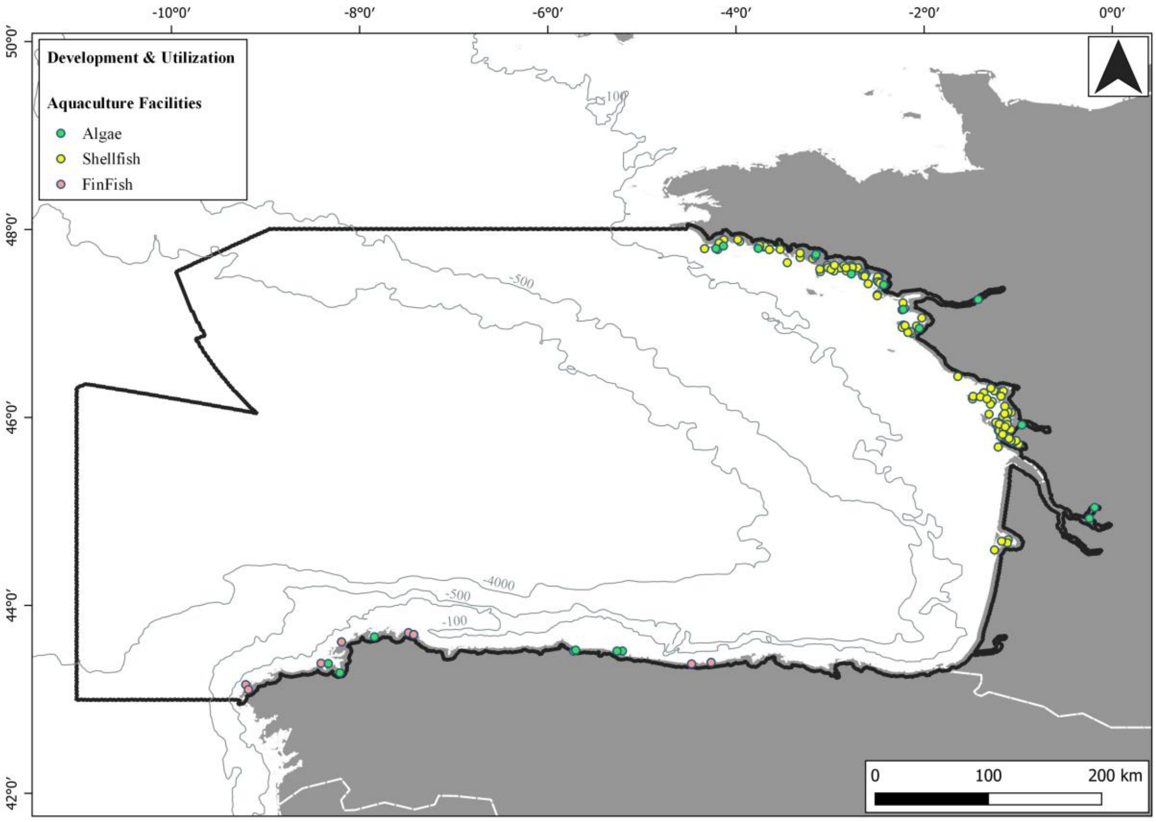

Figure 13. Location of aquaculture facilities.

3.2.3 Ports and future construction

Seventeen ports were located within the case study, nine in France and eight in Spain (Figure 14). This figure only includes the main commercial ports, but many other small ports (fishing ports, recreational ports) can be found in the case study.

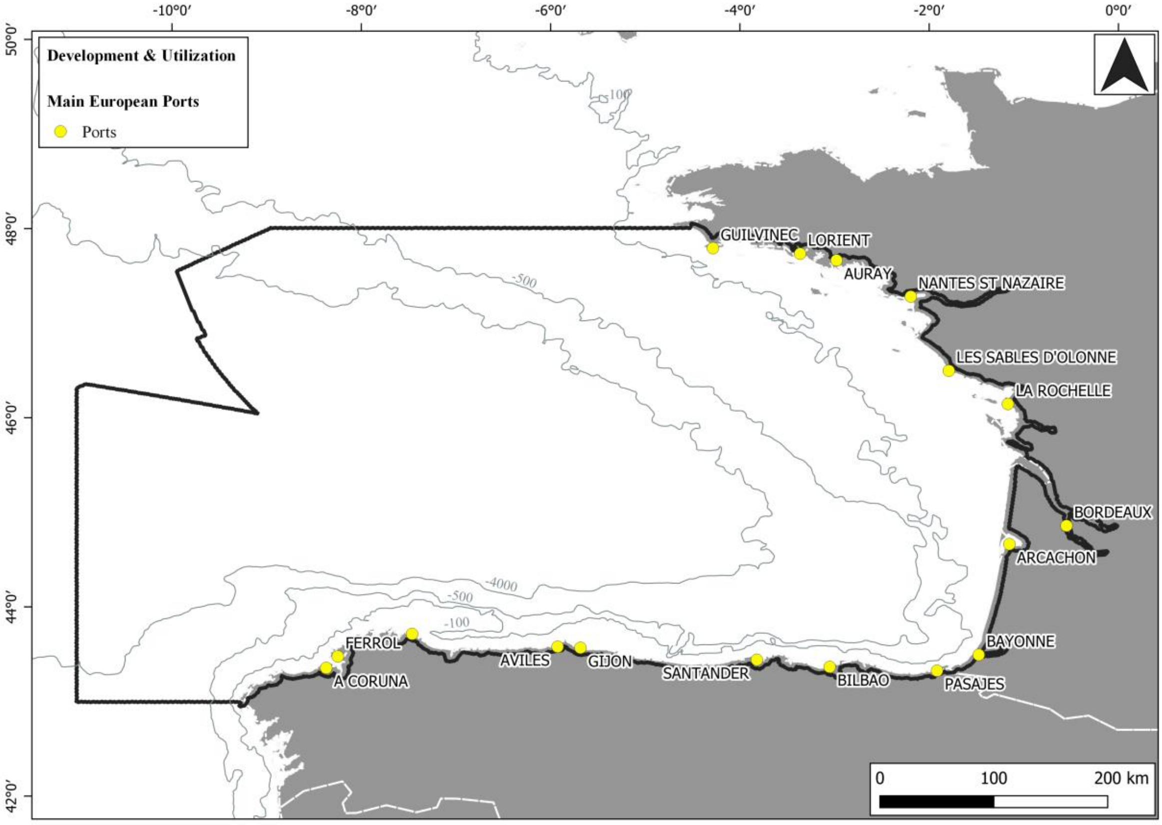

Figure 14. Location of the main commercial ports within the case study.

3.2.4 Operational and future ocean energy production facilities: wind power, wave and tidal energy

Four wind farms and four ocean energy test sites are located within the case study (Figure 15).

From the four wind farms, one is in Spain and three in France. Currently, the three wind farms in France are planned but not operational, while the one in Spain is operational. These facilities occupy a total area of 283 km^2 (0.1% of the case study area).

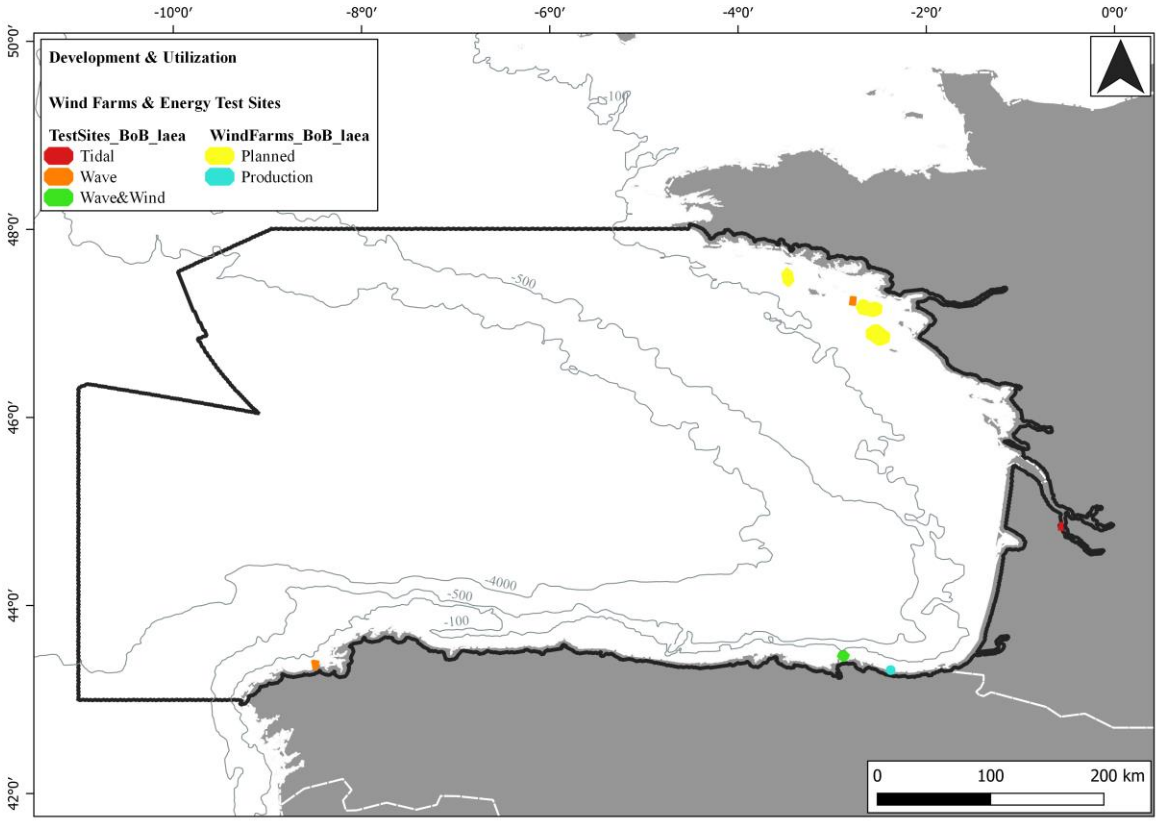

Figure 15. Location of offshore wind farms and ocean energy test sites.

Regarding the test sites, two are in Spain (one for waves and one for waves and wind) and two in France (one for waves and one for tidal energy) (Figure 15). These facilities occupy a total area of 24 km^2 in the case study grid.

Point-format information on other wind farms[41] and ocean energy projects[42] is available from EMODnet Human Activities. However, in the case of wind farms, most of them correspond to farms in early stage of planning, and therefore, with no information on the extension. Regarding ocean energy projects, some of them correspond to tests sites or projects not operational, finished or cancelled. Therefore, we did not consider these sources of information in the analysis.

[41] https://www.emodnet-humanactivities.eu/search-results.php?dataname=Wind+Farms+%28Points%29
[42] https://www.emodnet-humanactivities.eu/search-results.php?dataname=Project+Locations

3.2.5 Aggregate extraction and dredging sites

A total of 31 aggregate extraction areas are located within the study area. All of them are in France, covering a total area of 1,283 km^2 in the case study grid (Figure 16). A total of 191 dredging points and sediment disposal areas have been reported to EMODnet, 77 in France and 114 in Spain. Most of them are harbour maintenance and the associated sediment disposal areas in the coastal area.

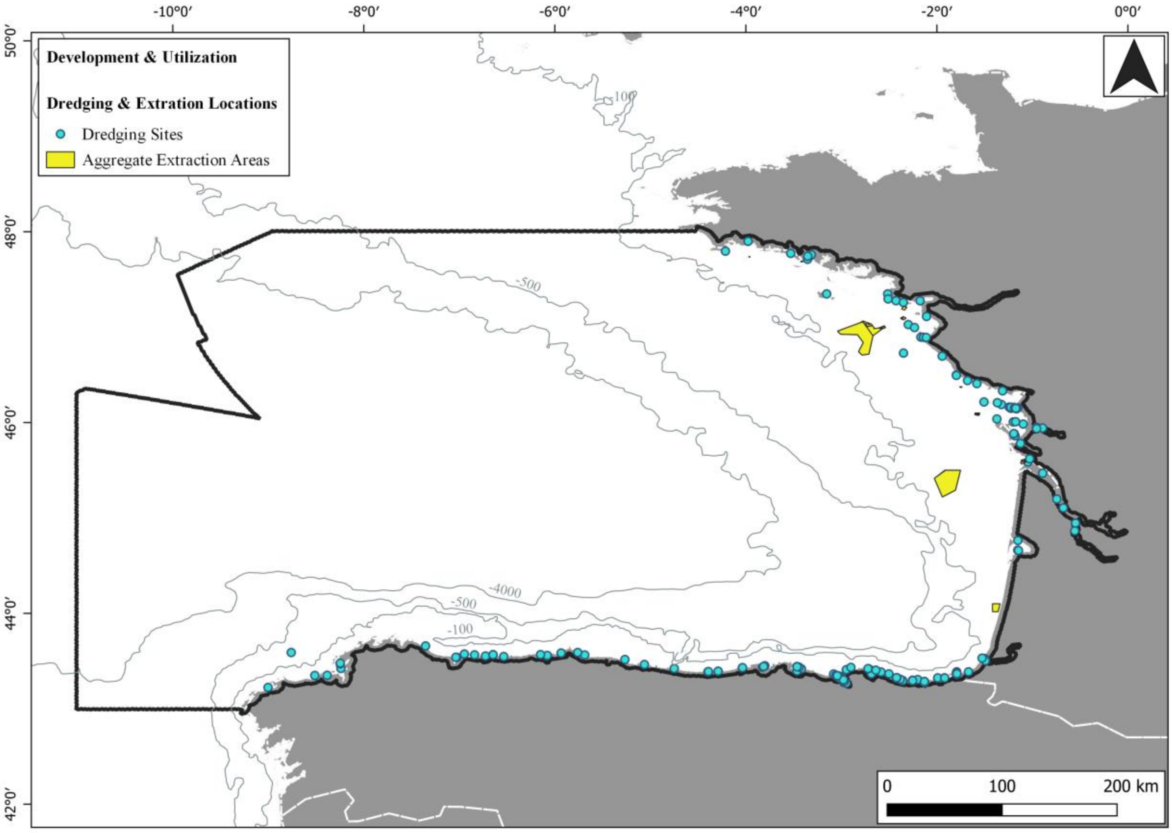

Figure 16. Location of dredging and disposal sites and aggregate extraction areas.

3.2.6 Fisheries

The fishing activity has been characterized using fishing intensity, estimated with data on fishing hours. Figure shows that most of the activity occurs close to the coast of France (see 'High' importance areas in (Figure 17). There is also a 'High' and 'Mid' fishing activity parallel to the 500 m isobath, in the slope of the continental shelf. Some 'Mid' importance areas appear in the Spanish coast, between the 500 m and 4,000 m isobaths.

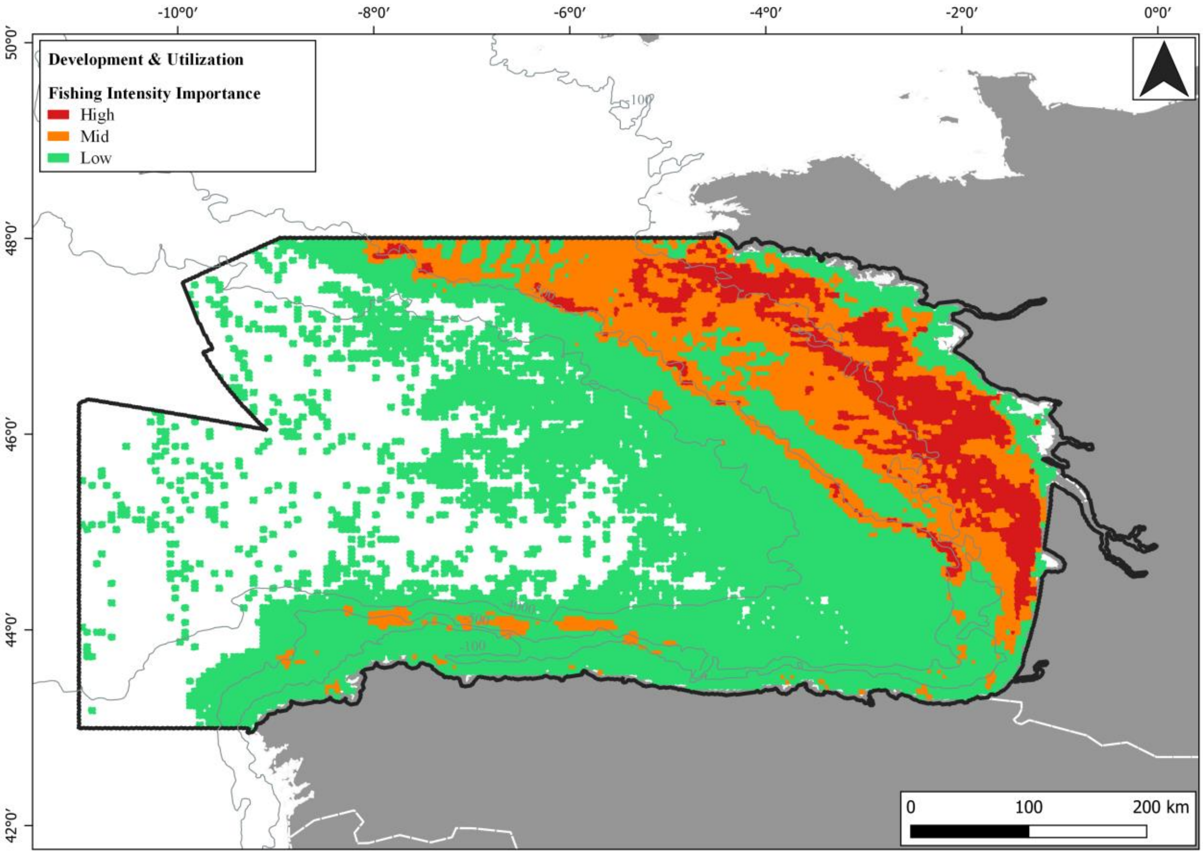

Figure 17. Fishing importance, estimated with fishing activity intensity (averaged number of fishing hours)

3.2.7 Military areas

The information on military areas was only available for Spain. Six areas were located within the case study area (Figure 18), four were for air force exercise and two for underwater exercise. After checking for overlaps between areas, the total area covered by military use within the case study was 23,890 km^2 (6.6%).

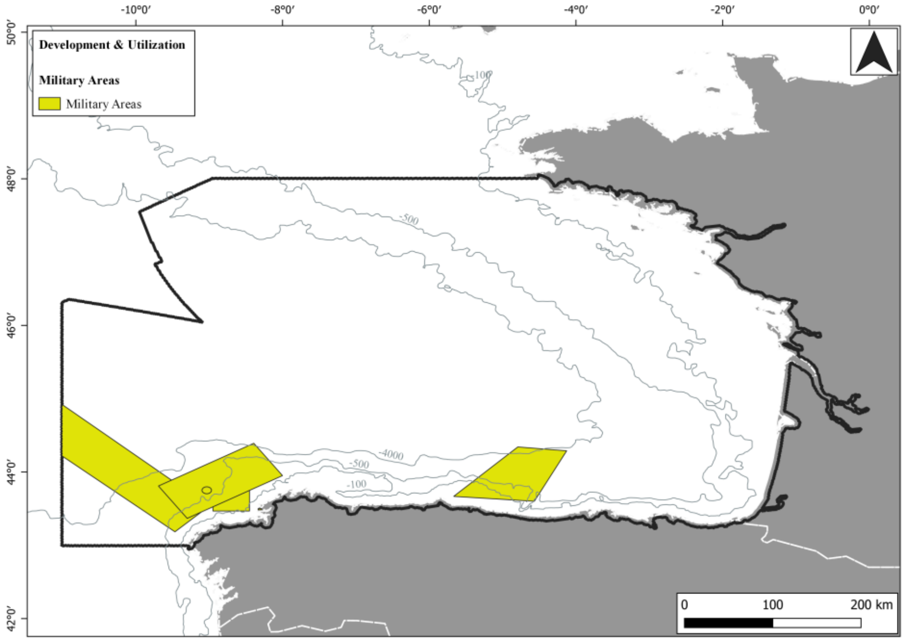

Figure 18. Location of military areas.

3.2.8 Tourism and recreation

The characterization of the tourism and recreation was done according to two indicators: location of bathing waters and recreational vessel density. In total, 909 bathing waters are located within the case study (Figure 19), 328 in Spain and 581 in France. Some of them occur in the same grid cell. Therefore, a total of 791 km^2 contain bathing waters.

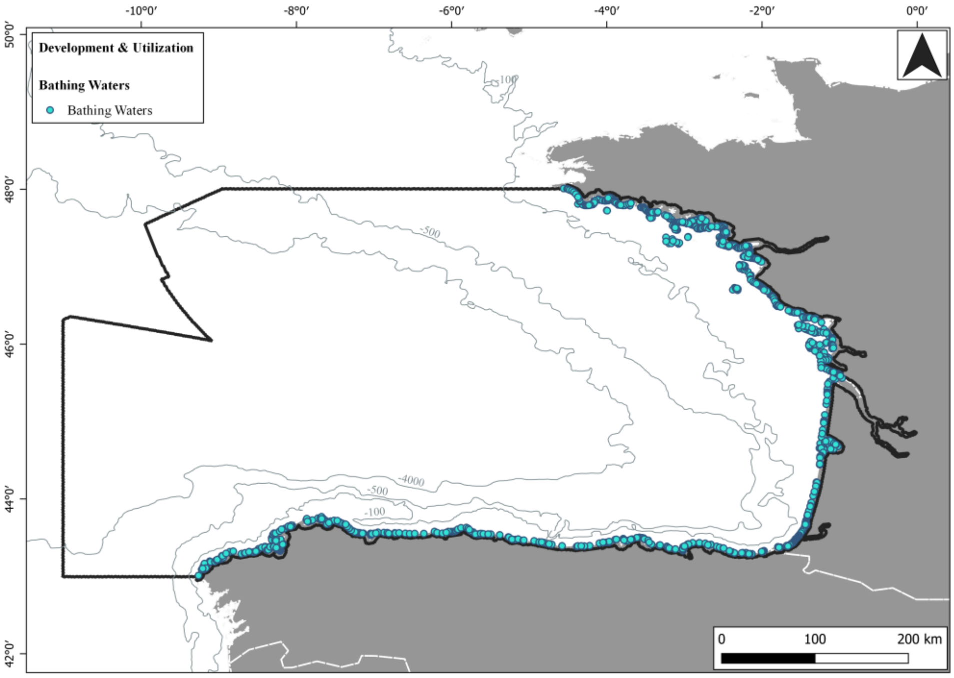

Figure 19. Location of bathing waters within the case study area.

Recreational vessel density contains information on pleasure crafts and sailing vessels. After discretization of the vessel density map (unit: average of hours per km^2 per month), a total of 18,918 km^2 were characterized as 'High' importance areas (i.e., high intensity in terms of recreational vessel density), 37,835 km^2 as 'Mid' importance areas and 132,423 km^2 as 'Low' importance areas (Figure 20). The remaining 175,462 km^2 were considered equal to zero, in terms of recreational vessel density.

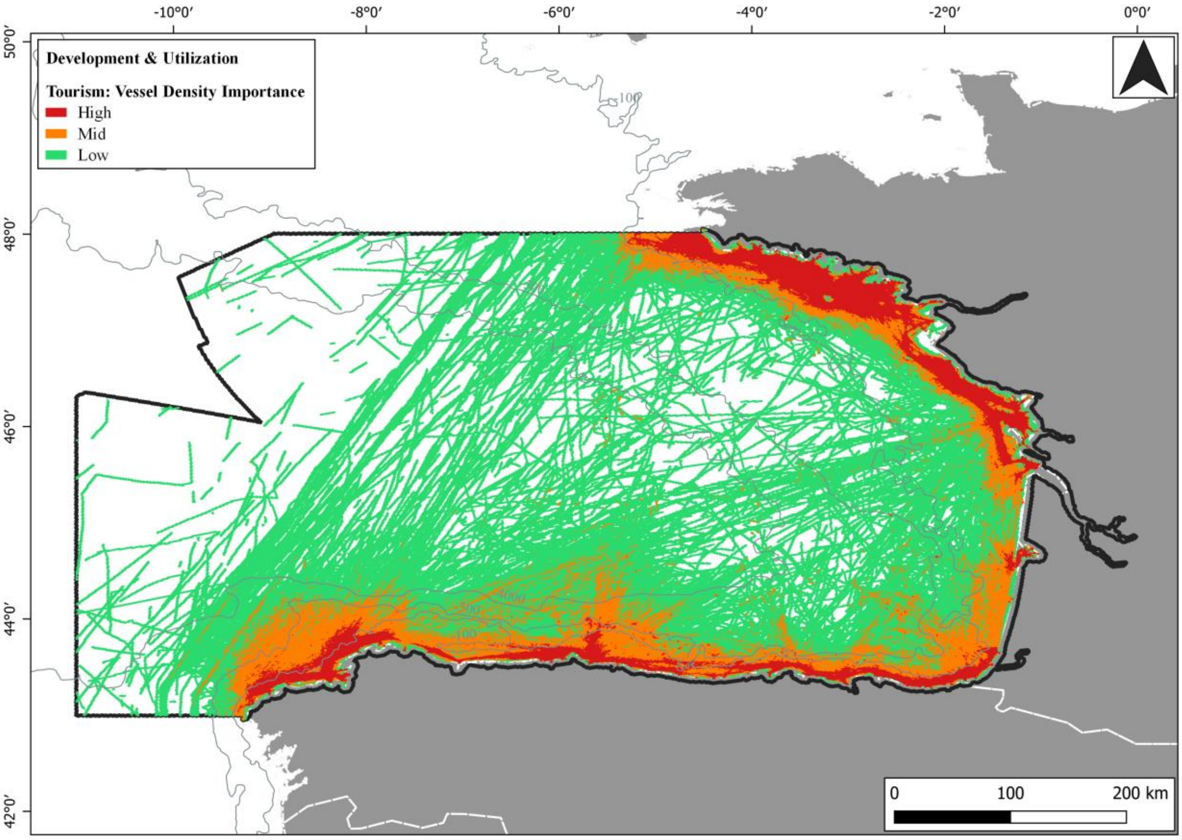

Figure 20. Importance of recreational vessel density.

3.2.9 Shipping

Shipping activity was characterized according to two aggregated indicators: vessel density and vessel route density of tanker, cargo and passenger vessel subtypes. The two indicators (Figure 21 and Figure 22) show a similar pattern, with two high intensity areas in (i) the coastal waters of Spain; and (ii) an area that crosses the case study from the southwest limit (i.e., Portugal) to the northern limit. The 9% of the case study was classified as of 'High' importance for vessel density, and for the route density.

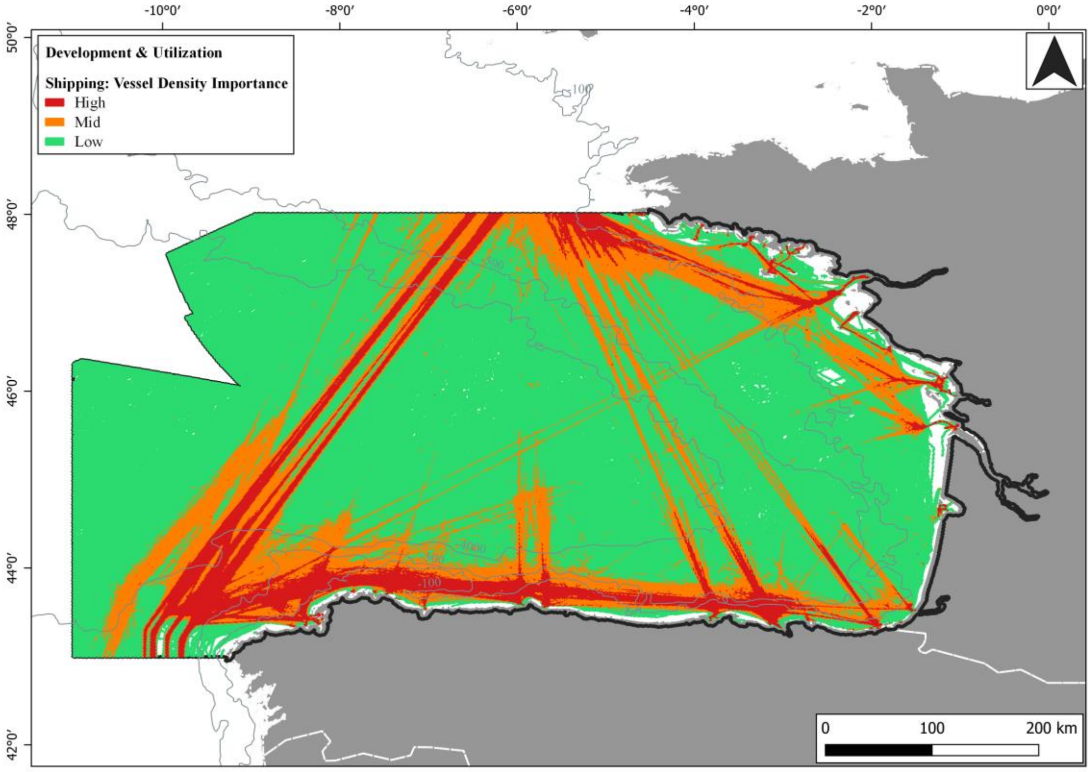

Figure 21. Shipping vessel density.

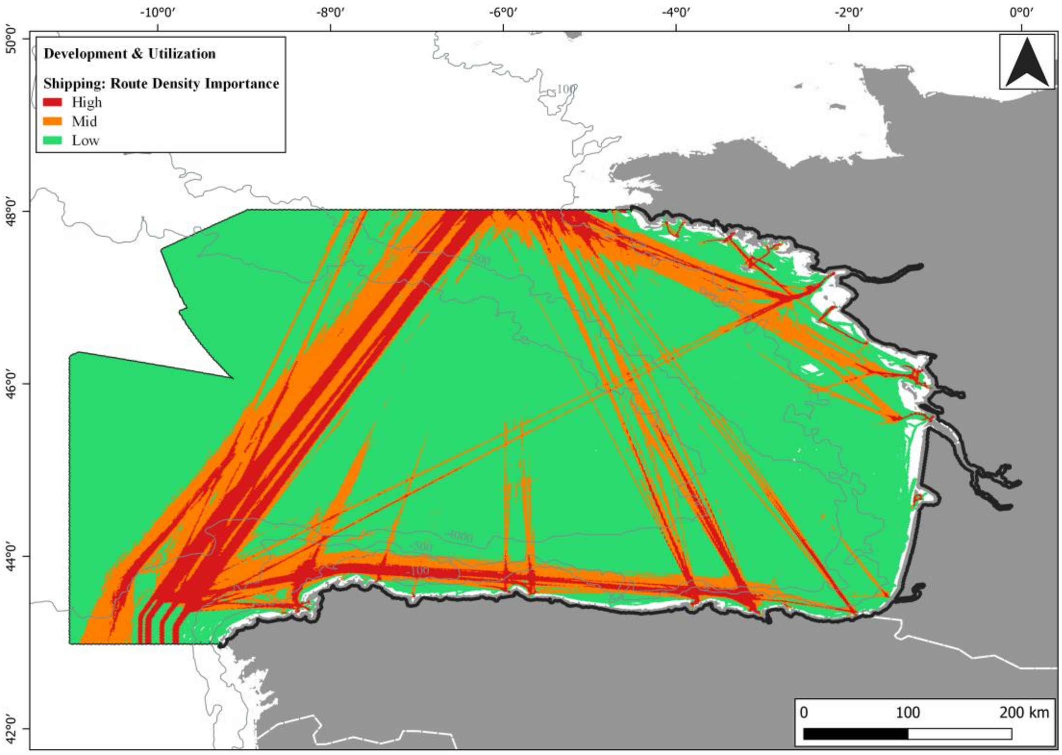

Figure 22. Shipping vessel route density.

3.2.10 Aggregated assessment of human activities

The aggregation of the 'importance' indicators of the eight activities (without including protected areas) shows that the Bay of Biscay is an area with a high concentration of human activities (Figure 23). Hence, 26% of the area was classified as 'High', 27% as 'Mid' and 45% as 'Low' importance area, for human activities. In the remaining 3% of cells no human activity was detected (Figure 23).

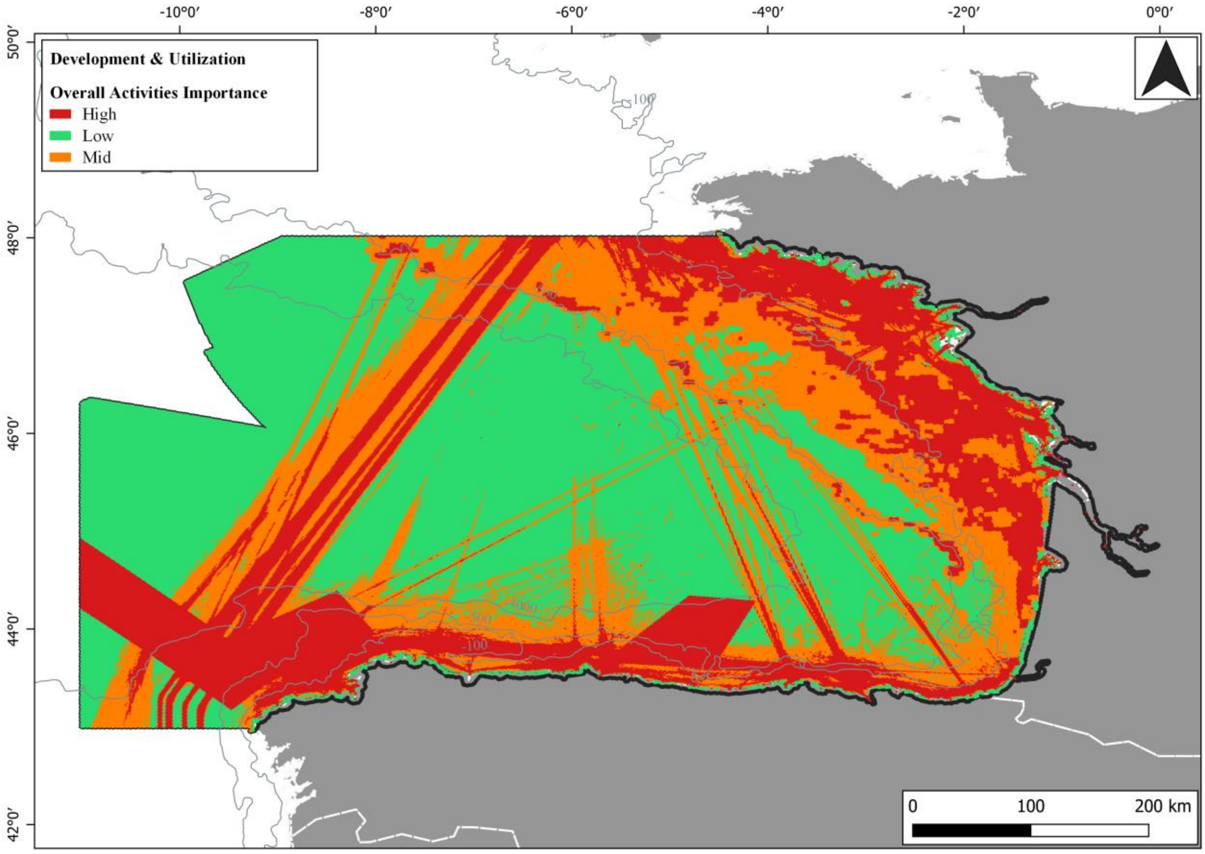

Figure 23. Importance of human activities: aggregated assessment of eight activities.

When activities were analysed individually (Table 11), shipping, fishing and tourism were the activities occupying the largest areas (95%, 66% and 52%, respectively, when adding 'High', 'Mid' and 'Low' activity). However, these activities were analysed with dynamic indicators (e.g., vessel density and vessel route density), meaning that the occupation is not constant and has not the same intensity throughout the year in all the cells. Indeed, when those activities are analysed considering only the cells with 'High' and 'Mid' importance values for human activities, the percentages were reduced from 95% to 34% for shipping, from 92% to 20% for fishing and from 52% to 16% for tourism. Protected areas, which were analysed independently, occupied 24% of the case study.

Table 11. Case study area (in km² and percentage) covered by each human activity, including High (H), Mid (M) and Low (L) importance, as well as not present.
****Aggregated values for human activities include all human activities except protected areas.***

Human activity		Total		Total (H, M, L)	
Type	Importance	km²	%	km²	%
Protected areas	High	88,698	24.3		
	Not present	275,940	75.7		
Aquaculture	High	146	0		
	Not present	364,492	99.9		
Ports	High	17	0		
	Not present	364,621	100		
Energy facilities	High	307	0.1		
	Not present	364,331	99.9		
Aggregate extraction and dredging	High	1,433	0.4		
	Not present	363,205	99.6		
Fishing	High	24,219	6.6	222,209	66.4
	Mid	48,436	13.3		
	Low	169,554	46.5		
	Not present	31,036	8.5		
Military area	High	23,890	6.5		
	Not present	340,748	93.4		
Tourism	High	19,407	5.3	189,385	51.8
	Mid	37,714	10.3		
	Low	132,264	36.2		
	Not present	175,253	48.1		
Shipping	High	42,835	11.7	344,916	94.5
	Mid	79,299	21.7		
	Low	222,782	61.1		
	Not present	19,722	5.4		
Human Activities - Aggregated*	High	93,844	25.7	355,120	97.4
	Mid	97,285	26.7		
	Low	163,991	45.0		
	Not present	9,518	2.6		

The number of human activities per km² ranged from zero to five (Figure 24). In most of the cells, the number of activities was three (34% of the case study) or four (37% of the case study). The two large areas in the Spanish coast with ~four activities correspond with the two military areas.

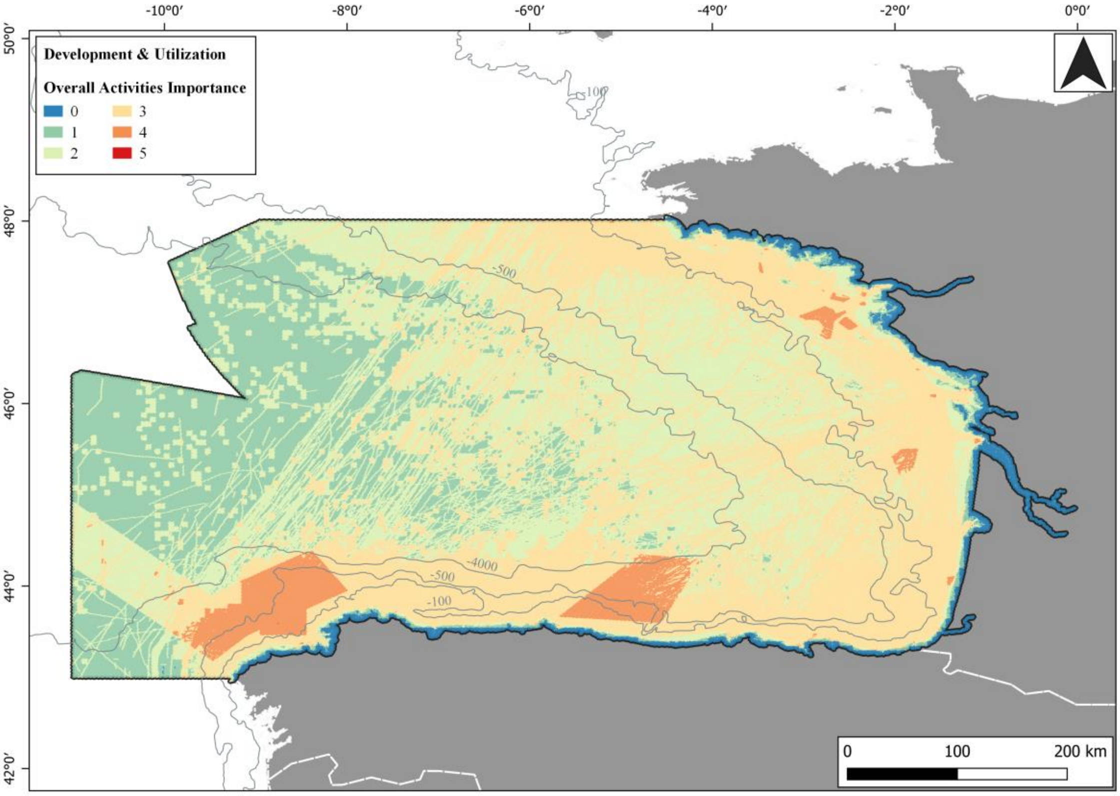

Figure 24. Importance of human activities: number of human activities per km².
The total number of human activities included is eight: aquaculture, ports, ocean energy, aggregate extraction and dredging, fishing, military areas, tourism and shipping.

3.3 Risk identification and evaluation of carrying capacity.

3.3.1 Marine ecological protection vs. marine utilization

When intersecting the human activities with the MEP results in the study area, the highest importance value is found for protected areas (presence –'High' importance- for MPAs and high importance for MEP is 9.6% of the Bay) (Table 12). However, some activities harmful for the environment, such as fishing, with high or mid importance, are occurring in areas of 'High' MEP interest (9.6%). In total, when aggregating all the activities, except MPAs, more than 74,857 km^2 (20.1% of the Bay) include activities undertaken in areas of 'High' importance for MEP, and 16.6% in areas of 'Mid' MEP importance (Table 12).

Table 12. Case study area (in km² and percentage) covered by each human activity, and according to marine ecological protection importance.
**Aggregated values for human activities include all human activities except protected areas.*

Marine utilization		Marine Ecological Protection					
		High		Mid		Low	
Type	Importance	km²	%	km²	%	km²	%
Protected areas	High	35,085	9.6	15,342	4.2	38,271	10.5
Aquaculture	High	137	0.0	7	0.0	2	0.0
Ports	High	16	0.0	0	0.0	1	0.0
Energy	High	306	0.1	0	0.0	1	0.0
Aggregate extraction and dredging	High	1,346	0.4	84	0.0	3	0.0
Fishing	High	14,400	3.9	8,474	2.3	1,345	0.4
	Mid	20,657	5.7	17,160	4.7	10,619	2.9
	Low	37,932	10.4	30,855	8.5	100,767	27.6
Military area	High	5,193	1.4	10,73	2.9	7,967	2.2
Tourism	High	14,610	4.0	4,755	1.3	42	0.0
	Mid	22,841	6.3	11,986	3.3	2,887	0.8
	Low	25,186	6.9	30,257	8.3	76,821	21.1
Shipping	High	14,118	3.9	11,395	3.1	17,322	4.8
	Mid	20,575	5.6	18,183	5.0	40,541	11.1
	Low	31,347	8.6	29,821	8.2	161,614	44.3
Human Activities - Aggregated*	High	39,764	11.1	28,108	7.7	25,972	7.1
	Mid	25,095	6.9	23,497	6.4	48,693	13.4
	Low	9,998	2.7	8,989	2.5	145,004	39.8
Total area with human activities (without protected areas)		**74,857**	**20.5**	**60,594**	**16.6**	**219,669**	**60.2**

After intersecting them, it is possible to determine the risk caused by these eight marine activities on the MEP, using the method in Section 2.2.3.3. Most of the High and Mid risk areas are located relatively close to the coast, on the continental shelf (Figure 25).

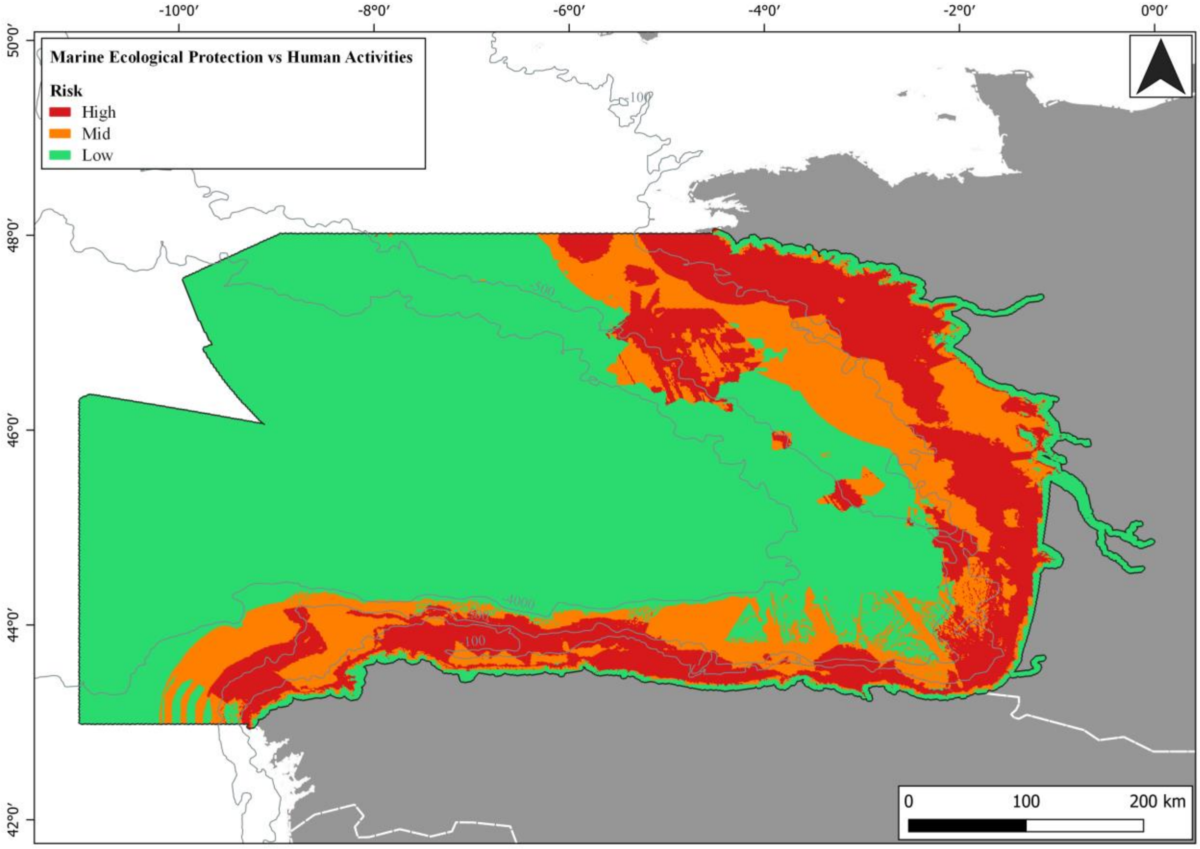

Figure 25. Risk identification, by comparing the importance for Marine Ecological Protection Importance vs. Human activities.

According to the results, 17.8% of the case study was at 'High' risk and 17% at 'Mid' risk (Table 13). A total of 238,176 km^2 (65.3% case study) were classified as 'Low' risk areas, either because (i) the MEP importance was 'Low' for any category of Human Activity Importance; (ii) the MEP importance was 'Mid' and the importance of human activities was 'Low'; or (iii) no human activity was detected in the cell.

Table 13. Case study areas (km^2 and percentage) by Risk and Marine Ecological Protection values.

Risk	Marine Ecological Protection Importance					
	High		Mid		Low	
	km^2	%	km^2	%	km^2	%
High	64,859	17.8	0	0.0	0	0.0
Mid	9,998	2.7	51,605	14.2	0	0.0
Low	6,902	1.9	10,233	2.8	221,041	60.6

The number of human activities occurring within 'High' risk areas is represented in Figure 26. From the 64,859 km^2 classified as 'High' risk areas (17.8% of the case study), 98.4% have 2, 3 or 4 human activities (11,663, 45,321, and 6,807 km^2, respectively) (Table 13).

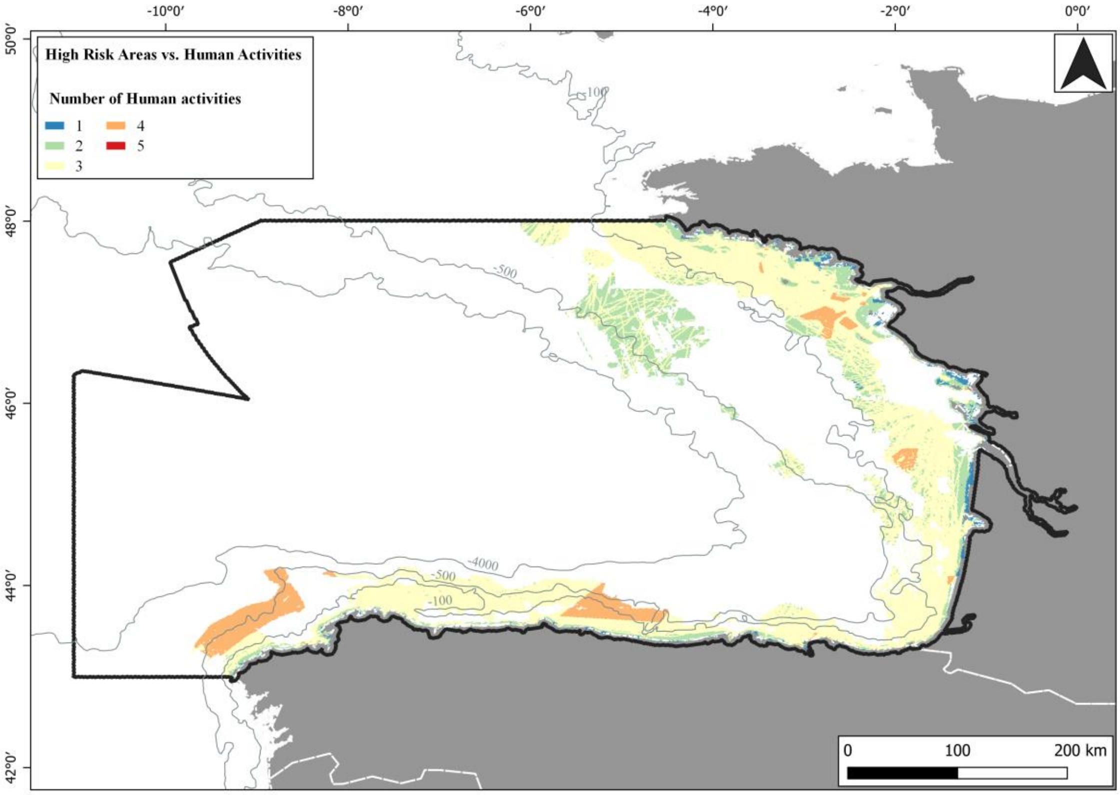

Figure 26. Number of Human activities within 'High' risk areas.

Table 14. Area occupied (km²) by different number of human activities (0-5) and classified according to Risk values (High, Mid, Low).

	Number of human activities and km² affected					
Risk	**0**	**1**	**2**	**3**	**4**	**5**
High	0	1,064	11,663	45,321	6,807	4
Mid	0	2,795	15,485	35,215	8,107	0
Low	9,518	71,031	101,595	55,490	542	0

3.3.2 Marine Ecological Protection vs. Fishing

To compare the MEP values with the fishing activity in the Bay of Biscay, first, we analysed the level of fishing activity within areas classified as of 'High' MEP importance (Figure 27). From the 81,759 km² classified as 'High' importance area for MEP, more than the 66% was classified as 'High' or 'Mid' importance area for fishing activity.

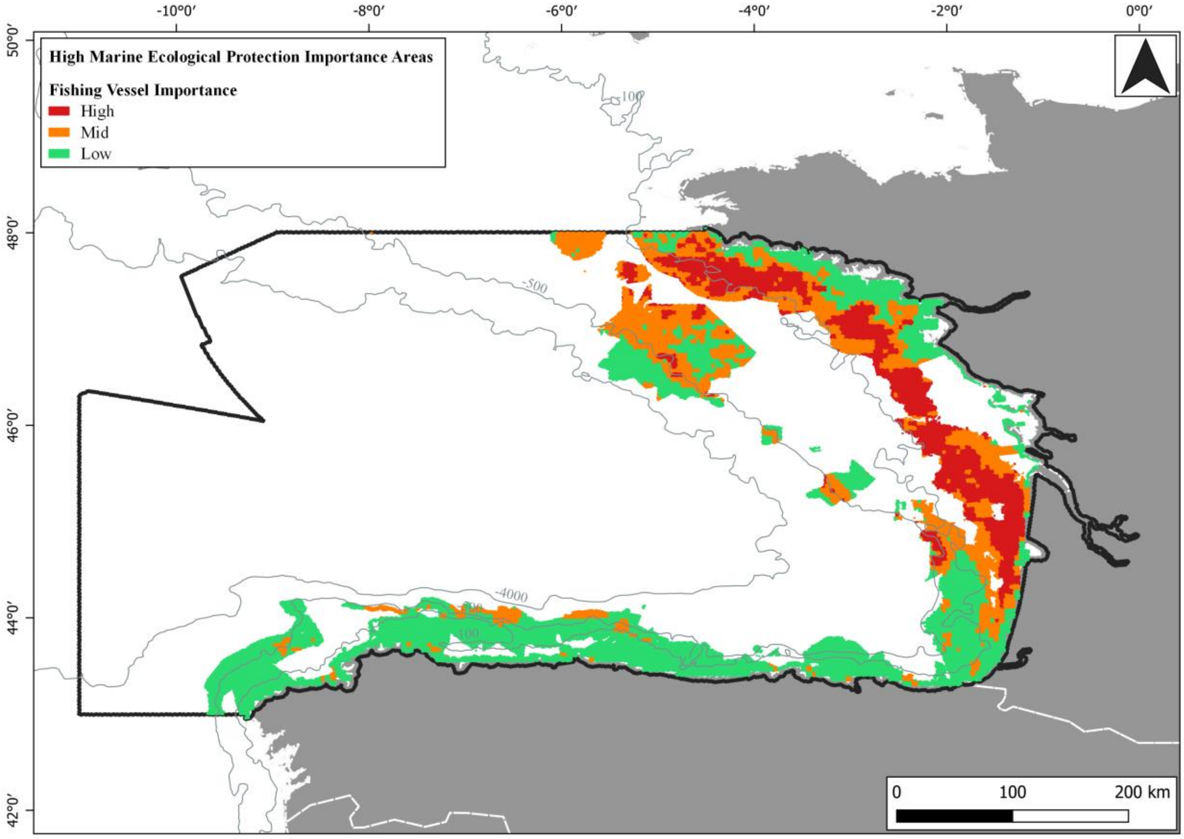

Figure 27. Fishing vessel density (High, Mid, Low) in areas of 'High Importance' Marine Ecological Protection areas.

Secondly, the MEP Importance values within 'High' or 'Mid' importance areas for fishing activity were analysed (Figure 28). In this case, results suggest that from the 105,712 km^2 important for fishing, most of them (52%) are classified as 'High' according to MEP, while 32% and 17% are classified as 'Mid' and 'Low' MEP importance, respectively.

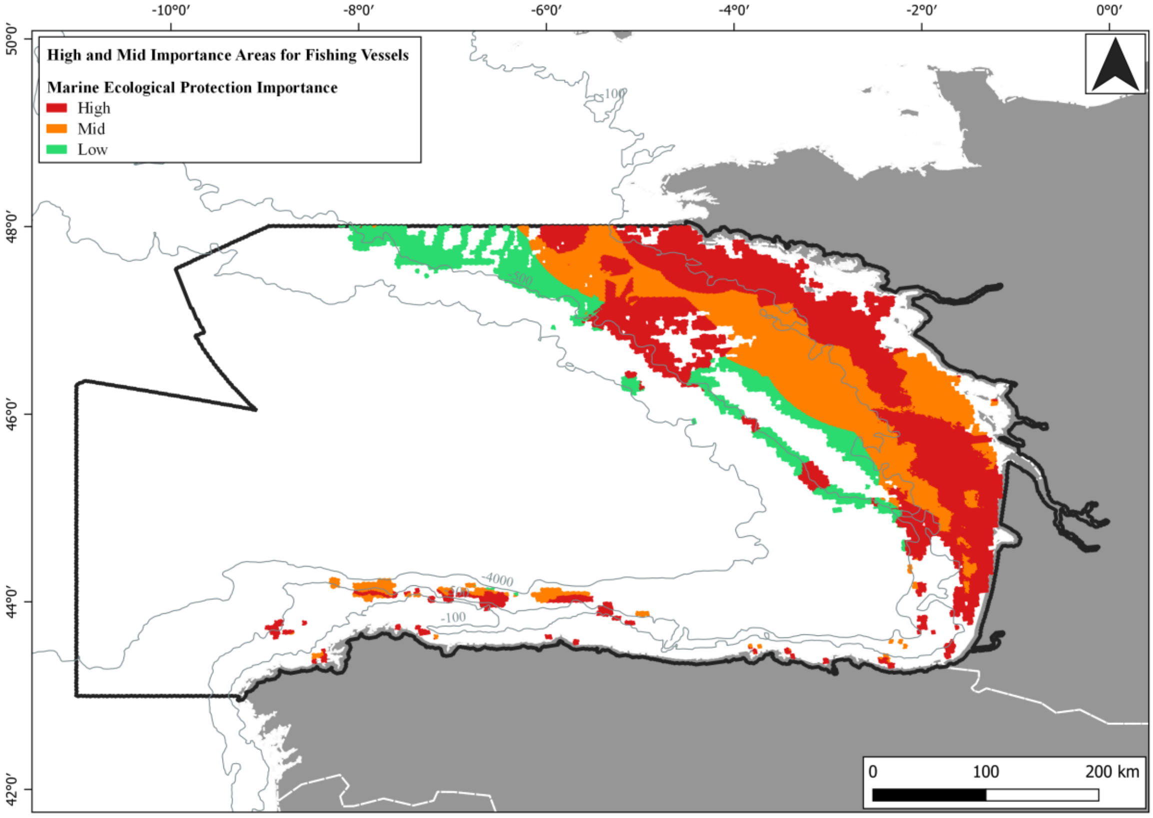

Figure 28. Importance for Marine Ecological Protection within areas with High or Mid fishing activity, including the two indicators used.

3.3.3 Marine Ecological Protection vs. Marine Protected Areas and MRECC

Marine Protected Areas occupied a total of 88,698 km^2. Of them, 40% (35,085 km^2) were classified as 'High' MEP importance, 17% (15,342 km^2) as 'Mid' importance and 43% (38,271 km^2) as 'Low' importance (Figure 29).

The highest extension of marine protected areas classified as of 'Low' MEP importance are within two Natura2000 SPA sites in French waters, more precisely the SPA sites "Mers Celtiques- Talus du Golfe de Gascogne" (Natura2000 site code: FR5212016) and 'Tête de Canyon du Cap Ferret' (Natura2000 site code: FR7212019).

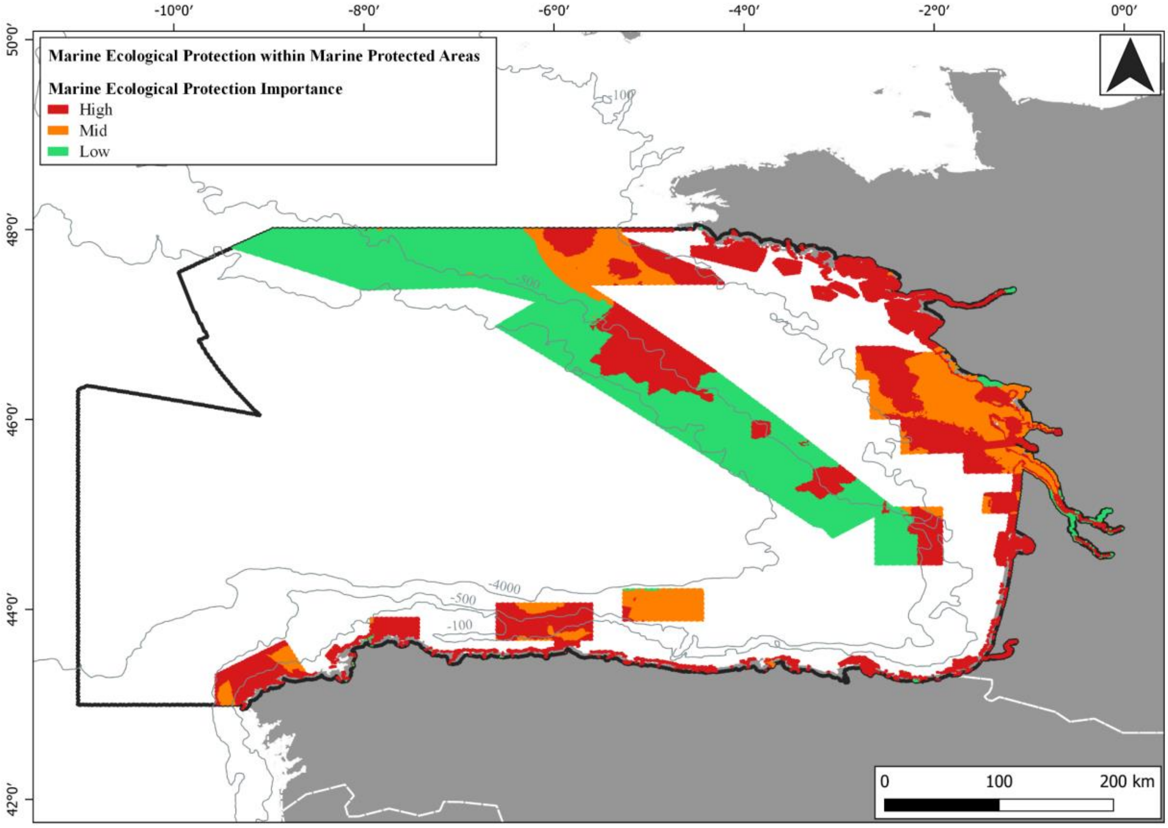

Figure 29. Marine Ecological Protection Importance (High, Mid, Low) within Marine Protected Areas.

Finally, the MRECC was calculated as the area in which neither MPAs nor high MEP importance exist (Figure 30). Since the total area covered by both is 135,372 km^2, the available MRECC within the Bay of Biscay is 229,266 km^2.

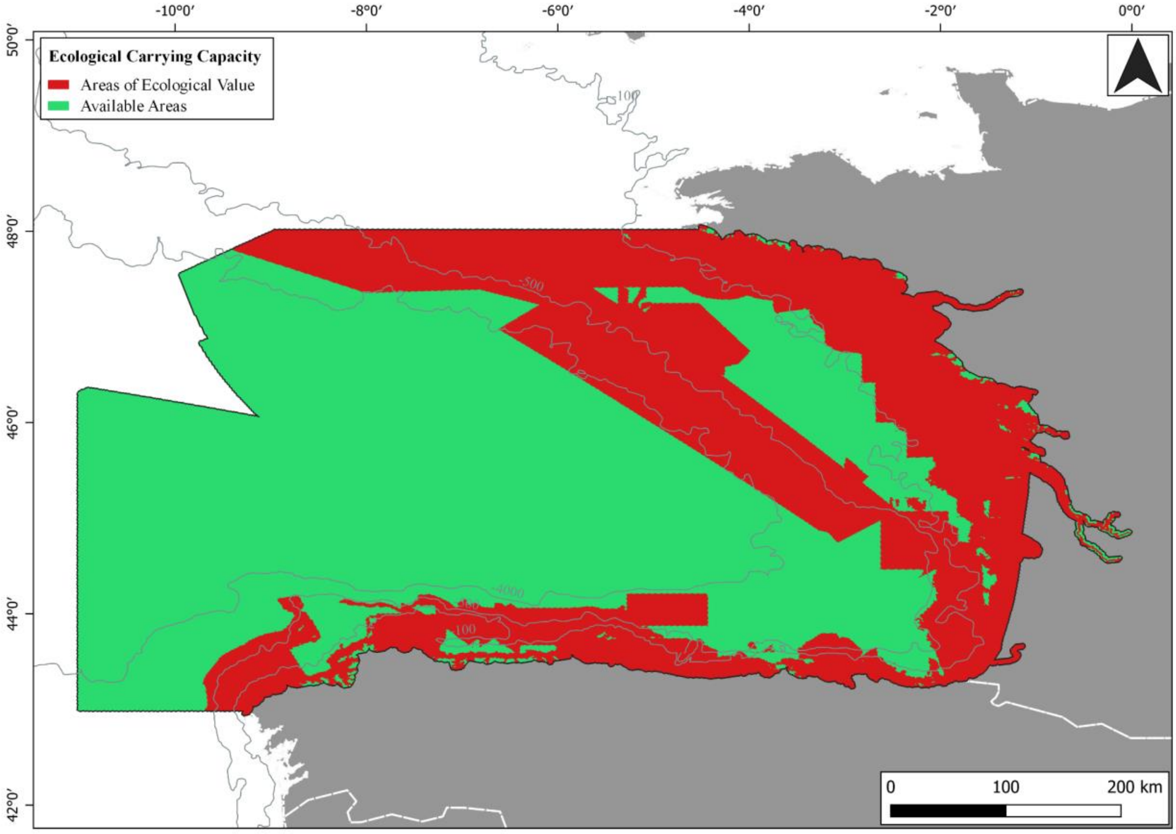

Figure 30. Marine Resource-Environment Carrying Capacity (in green) within the Bay of Biscay.

4 Discussion

Adapting the China's methodology in Europe was a challenge. Although environmental carrying capacity methods have been used in Europe for cities (Świąder et al., 2020), the circumstances are different for marine ecosystems. The terminology used in China sometimes has not a similar use in Europe (e.g. 'importance for life –history stages of species'), in other cases the philosophy behind the method is different, despite the fact that the name could be the same (e.g. 'marine ecological protection'), or sometimes the habitats (e.g. mangroves) or threats (e.g. 'marine disasters') are inexistent or totally different. These facts require an adaptation of the methodology to European standards, for which the MSFD (European Commission, 2008) and the MSPD (European Union, 2014), seem to be the closest references. This is because they aim at protecting the ocean, by making sustainable use of the marine resources (within the MSFD), and at the same time promoting the blue economy, by maritime spatial planning (within the MSPD) (Elliott et al., 2018; European Commission, 2020; Stelzenmüller et al., 2020).

Although this adaptation can be done to some extent, and the extensive experience of China in marine waters is of help (e.g. Di et al., 2007; Fuju et al., 2011; Liao et al., 2013; Liu et al., 2020), the application of the double evaluation methodology to the Bay of Biscay has shown some limitations, and also interesting results, which are discussed below, taking into account the three main parts of the method.

4.1 Marine ecological protection

The collation of information from different ecosystem components is essential for taking decisions on the future human activities that can be carried out in an area, as well as in their planning and management (Issaris et al., 2012). However, some methodological problems have been faced during the process of analysis of the MEP:

- Lack of data: sometimes, there is a total absence of data (e.g., information on aquatic genetic resources), in other cases the information can be fragmentary (e.g., some unique habitats, especially in deep-sea areas), and in some cases data are qualitative (e.g., presence/absence), making in all cases difficult to evaluate the required information in a quantitative and accurate way.
- Scale of the information available: the grid used was 1x1 km, but sometimes the scale of the information available was too broad (e.g., several kilometres, for some species with an ample distribution, such as mammals) or too small (point data layers, for ports) to provide useful insights in the methodology.
- Specific indicators used in the analysis: despite the adaptation of the indicators used in Europe, in some cases it was difficult to translate them in the case study with the available information and, thus, expert judgment needs to be used (e.g., how to determine the importance of the distribution area of a species).

Sometimes, there are specific issues, associated to one of the methodological problems abovementioned. At the species level, to determine the importance of distribution area of megafauna, we selected the IUCN spatial information and Birdlife International, from which the spatial distribution of species of interest can be extracted. However, IUCN layers have low specificity, showing presence-absence of species within the Red List, with large distributions (Jefferson et al., 2021). Some more accurate estimations for mammals and seabirds' distribution exist (e.g., Waggitt et al., 2020). However, the number of species and the low correspondence with species of interest for conservation (e.g. after Oslo-Paris Convention, or Birds and Habitats Directives), make difficult to use that dataset.

Hence, it would be necessary to improve this part of the assessment in the future, when better information becomes available.

In the case of habitats, the fishery growing areas have been selected based on five of the most important commercial species in the Bay of Biscay, in terms of landings and economical value, representing more than 40% of total weight of landings and 30% of the total value of landings (STECF, 2019). This makes the analysis robust enough; however, only egg surveys have been considered, since for juvenile recruitment areas there is a lack of data for some species, although they can be of high interest for the marine protection (Irigoien et al., 2008).

For coastal protection and vulnerability data from Liquete et al. (2013) have been used. The objective of Liquete et al. (2013) was to estimate the coastal protection as an ecosystem service in Europe. For it, they defined three indicators: 'capacity', 'natural exposure', and 'human demand' of coastal protection. The definition and approach followed to determine the coastal protection 'capacity' for coastal protection by Liquete et al. (2013) can be considered equivalent to the 'coastal protection' in the Chinese method. Regarding 'coastal vulnerability' as defined by the Chinese method, it could be considered similar to 'natural exposure' in Liquete et al. (2013); however, coastal vulnerability considers the erosion rate, and 'natural exposure' in Liquete et al. (2013) did not. Despite this difference, we used natural exposure values as defined in Liquete et al. (2013) to estimate coastal vulnerability because the objective of both indicators is similar, and the information is accurate and useful in this context.

Finally, the aggregation method used to integrate the different indicators ("One high importance, all high importance") is quite stringent, with no discrimination between areas of higher importance, due to the absence of good maps of abundance in the case of species or habitats status. To solve this, weighting factors can be applied to give more importance to certain indicators, as it is done when assessing the status in an integrative way (e.g. Levin et al., 2009; Langhans et al., 2014; Uusitalo et al., 2016), or to assign a higher MEP importance to areas where more than one component appears (e.g., a single cell where both a unique habitat, such as deep-sea sponge aggregations, and spawning ground of a commercial species can be found) .

Despite the limitations of the methodology raised above, the aggregated assessment identified the most important ecological areas in the coastal zone, the continental shelf and the continental slope, coinciding with some of the assessments and recommendations undertook in the Bay of Biscay (Lavín et al., 2006; Galparsoro et al., 2014, 2020; García-Barón et al., 2020). However, leaving out of the study species not included in the OSPAR List of Threatened and/or Declining Species and Habitats, or in the Annex II of Habitats Directive, may have relevant implications. As an example, the case of the fin whale (*Balaenoptera physalus*), species for which the main critical area of distribution is in the south-eastern part of the Bay of Biscay, and which could be protected by the implementation of a transboundary MPA (García-Barón et al., 2019a). In fact, this species is considered as an indicator, within the functional group "marine mammals", for achieving the good environmental status under the MSFD, for the North-East Atlantic Ocean. On the other hand, it is difficult to properly assess the ecological importance of the extensive bathyal and abyssal area within the Bay, because sufficient data are lacking and the available data are old (Laubier and Monnot, 1985; Elizalde et al., 1993; van Denderen et al., 2021; Watling and Lapointe, 2022).

4.2 Current marine development and utilization

In the analysis of activities at sea, we have included a total of 8 out of the 11 activity themes included in the MSFD (European Commission, 2017) i.e., physical restructuring (ports), production of energy, cultivation of living resources, extraction of non-living resources (aggregate extraction, dredging and disposal), extraction of living resources (fisheries), security-defence (military areas), tourism and leisure, and transport (shipping). We have included a ninth activity (MPAs), which, although is a management activity, could be assimilable to 'education and research' under the European Commission (2017) list. Only the activity 'urban and industrial uses' has not been included. Hence, the main human activities within the Bay of Biscay, as defined by the MSFD, have been considered in the analysis of the MRECC.

The methodological problems when collating information for human activities (or current marine development and utilization) were like those in the previous section (e.g., data availability, layers creation, aggregation methodology, etc.). However, there are some specific problems associated to the use of the marine space. Some activities (e.g., aquaculture, ports, dredging sites, bathing waters) are represented by point data within the grid, when it is known that this does not represent the total extension of the activity, representing an underestimation of the total area covered by the activity (Solaun et al., 2021). In addition, in the case of ports, only main commercial ports have been included, when it is well-known the high number of small ports and marinas present within the Bay of Biscay.

Other problem refers to the activity itself and how to disentangle the activity from secondary data. For example, in the case of fisheries, the data used from EMODNet human activities come from the Vessel Monitoring System (VMS) (Marshall and Robert, 1998), in which disentangling the real fishing grounds from route data could be difficult, although its use has yielded good results in different studies (e.g., Campbell et al., 2014; Fernandes et al., 2019). Furthermore, not all the fishing activity can be characterized with VMS data, as not all the vessels are obliged to install them, e.g., small-scale fishing vessels fleet (<15 m long). This is an important gap due to the relevance of small-scale fishing vessels in the area (STECF, 2020), which can produce important pressures (Pascual et al., 2013).

As commented above, MPAs can be considered more a management activity to reduce pressures, rather than a human activity producing pressures; however, as this activity also requires space to be implemented, we have included it here, but analysed separately. Regarding Natura2000 areas, SPAs (under the Birds Directive) and SACs (under the Habitats Directive) have been included, but no Sites of Community Importance (SCIs), since these are proposals but not already established protected areas (Pinarbasi et al., 2020).

This fact leads to another limitation when applying the double evaluation methodology: in China, this method evaluates suitable spatial development areas, but not current ones (although some authors have used them, e.g. Ma et al., 2017). However, in the Bay of Biscay (both in France and Spain), the lack of information for development in all human activities, prevented the application of the original methodology and only current use was included.

Despite these limitations, the aggregation of human activities shows a gradient of use, from the intense use in coastal area, to the mid use in the continental shelf and the low use in the open sea (excepting the main shipping lanes and some areas used by fisheries). A similar gradient can be seen in the pressures produced by human activities, both at European level and in the Bay of Biscay, in a recent study by Korpinen et al. (2021). The human activity occupying the largest area is MPAs, which should serve to prevent the effects from pressures. The activities producing pressures and occupying the largest areas are shipping, fishing, military, and tourism, in that order, being the remaining anecdotic. This coincides with the most important pressures at sea, at European scale, in which, after climate change, the highest pressures are noise (coming from all those activities), fish catches (from fishing), or introduction of alien species (by shipping, tourism, etc.) (Korpinen et al., 2021).

4.3 Risk identification and evaluation of carrying capacity

When crossing MEP results and human activities, most of the MEP come from spawning areas for most important commercial fish (Ibaibarriaga et al., 2007). However, the ecological importance of these areas tends to be seasonal, and not necessarily incompatible with all human activities, e.g., anchovy spawning takes place from March to August, peaking in May (Erauskin-Extramiana et al., 2019). Hence, an activity such as sediment disposal in September will not affect it, or some activities, such as shipping, could be hardly assessed in relation to anchovy spawning. Hence, there is a problem in determining the real risk for MEP coming from human activities, and, for more accurate assessments, both the timing of the human activities throughout the year, and the coincidence or not with the MEP should be considered.

Also, although there are areas at high MEP risk, with different number of human activities, it seems that, the more activities in a cell, the more risk, with a peak in five human activities. However, not all these activities produce the same level of pressure. Usually, methods calculating the cumulative pressure effects integrate them without weighting the pressure effect (Ban et al., 2014; Korpinen et al., 2021). In other cases, weightings are applied to the sensitivity of the ecosystem components at risk (Halpern et al., 2015; Stelzenmüller et al., 2018), but very few, if any, consider the additive, synergistic or antagonistic effects of multiple pressures in MEP risk (Piggott et al., 2015; Teichert et al., 2016), which are not included in the methodology used here. In this sense, the method in the Bay of Biscay could be adapted to provide to each human activity a weighting factor, based on its potential to impact the environment, as well as its temporal incidence (e.g., constant, punctual, concentrated in certain season, etc.).

From the human activities studied, it is known that fishing could be one of the most extensive and pervasive human activities at sea, impacting different ecosystem components: overexploiting fish, producing damage in the benthic communities by trawling, increasing mortality in mammals or seabirds due to bycatch, altering the food webs or introducing noise and litter into the system (Lewinson et al., 2014; Halpern et al., 2019; Pitcher et al., 2022). Significant overlaps are produced between this activity and high importance areas for MEP (until 52% of fishing important areas are placed in them). In some cases, it is because the fishing activity takes place in areas where fish concentrate for spawning (e.g., anchovy can only be fished during March-June, because the rest of the time is dispersed (Motos et al., 1996)). However, in other cases, fishing grounds compete with migratory routes or feeding areas for mammals or seabirds, producing different threats to these faunistic groups in some periods of the year (Lewison et al., 2014; García-Barón et al., 2019b). The capacity of fishing activity to impact ecosystem components will differ depending on the fishing technique used, e.g., physical disturbance generated at benthic ecosystems is the main pressure produced by trawling vessels (Sciberras et al., 2016), while bycatch and lost gears are the main environmental problems generated by gillnet fleets (Shester and Micheli, 2011).

Hence, marine protection should be considered carefully when studying the human activities currently undertaken or likely to be developed. Currently, areas identified with this methodology as of high and mid importance for MEP, represent 57% of the total surface protected within the Bay of Biscay. In turn, 43% of the protected areas are of low importance and placed mostly in the French slope of the continental shelf. However, this area is known to be important for some megafauna in some periods of the year, e.g., for several species of dolphins or fin and pilot whales (Laran et al., 2017; García-Barón et al., 2019a; Waggitt et al., 2020). This means that the MEP methodology probably is underestimating the importance of some areas, just because some species are not included in the IUCN lists or there are not enough data. Maybe, the potential coexistence between human activities and protection, and the ways in which this should be established, could be undertaken in a management programme for the whole Bay of Biscay, like those approved by Member States within the MSFD (Cavallo et al., 2018).

In China, much research has been taken to calculate the carrying capacity from different perspectives and purposes (e.g. pollutants capacity, ecosystem health, sustainable ocean economy), including different approaches, such as Resource-Environment Carrying Capacity (Di et al., 2007; Liu et al., 2020; Zhao et al., 2021; Zhang and Niu, 2021), Environmental Carrying Capacity (Liao et al., 2013; Song and Du, 2019; Wang et al., 2021), or Ecological Carrying Capacity (Ma et al., 2017).

Here, we adapt the official technical guideline of China, which define MRECC as the maximum volume of human activities, and considering the available marine resources, and ecological and environmental elements. This method aims to determine the maximum capacity of human activities in an area, considering ecological protection requirements and regional resources present. In the case of Bay of Biscay, due to the lack of some data, we only consider the ecological protection, resources and environmental elements excluded. Hence, the MRECC refers to maximum space for all the marine human activities based on ecological protection requirements, of which the result seems to be a little broad and needs to be further refined by indicators of marine resources, environment or others, to acquire accurate MRECC of specific activities.

Besides, the application of double evaluation is a little different in China and Europe. In China, strict protection targets are included, and high importance areas for MEP are applied in MSP as a basis to delimit Marine Ecological Red Line areas (excluding some of current or potential development areas through ecological impact assessment) (Lu et al., 2015). In Europe, although this approach cannot be used directly in MSP, some of the steps of MSP seem analogous (Ehler and Douvere, 2009), and as such the method could provide some insights into this process. The MSPD (European Union, 2014) requires Member States to complete marine plans by 2021. In the case of France and Spain some work, comparing both plannings, has been done (Pinarbasi et al., 2020). Besides, adaptive management approaches should also be included when applying double evaluation, since some MEP evaluations are not static throughout the year (e.g., spawning grounds could be important in spring) and this kind of assumptions can prevent to determine appropriately the human activities that can be undertaken considering space and time scales. These problems could be overtaken through adequate management measures, allowing specific activities in different areas and season of the year.

4.4 Weighting the ecological elements and human activities

As discussed above, the methodology used here does not include the possibility of weighting either the MEP elements or the human activities, when calculating the risk and MRECC, representing a limitation of the method. Weighting factors, depending on the importance or sensitivity of certain indicators can be considered (e.g., Levin et al., 2009; Langhans et al., 2014; Uusitalo et al., 2016). In this section, we have used the sensitivity scores of 30 marine habitats and species against 15 anthropogenic pressures in Europe's seas, determined by Korpinen et al. (2021), to determine the differences in the method, when weighting or not. The scores range between 0 (not sensitive) and 5 (highly sensitive) for each single pressure. From the individual values provided by these authors, we have calculated the mean values of the 15 pressures for: (i) species of interest (including fish, birds, reptiles and mammals), with a score of 2.498; (ii) seagrasses, with 2.873; (iii) seaweeds, with 2.8; (iv) saltmarshes, with 2.57; (v) tidal flats-shallow waters, with 2.807; (v) estuaries, with 2.553; (vi) fishery growing areas, with 3.273; and (vii) unique habitats, with 2.931.

These scores have been multiplied by the numeric importance of each component in each grid cell (see Figure 5 and Table 10), transforming the 'High' importance to 3, 'Mid' importance to 2 and 'Low' importance to 1. The numeric values obtained for each component have been summed up, obtaining a unique value that comprises information on species and habitats, i.e., the value of marine biodiversity maintenance in each grid cell. This numeric value has been categorized using the percentiles 33rd and 67th (1/3 and 2/3) as "High Importance" (>2/3), "Mid Importance" (>1/3 and ≤2/3) and "Low Importance" (≤1/3).

In each grid cell, the MEP value with weighting factors was calculated as the highest value reported for any of the three components: the new marine biodiversity maintenance values, and the previous values for coastal protection and coastal vulnerability (Figure 31).

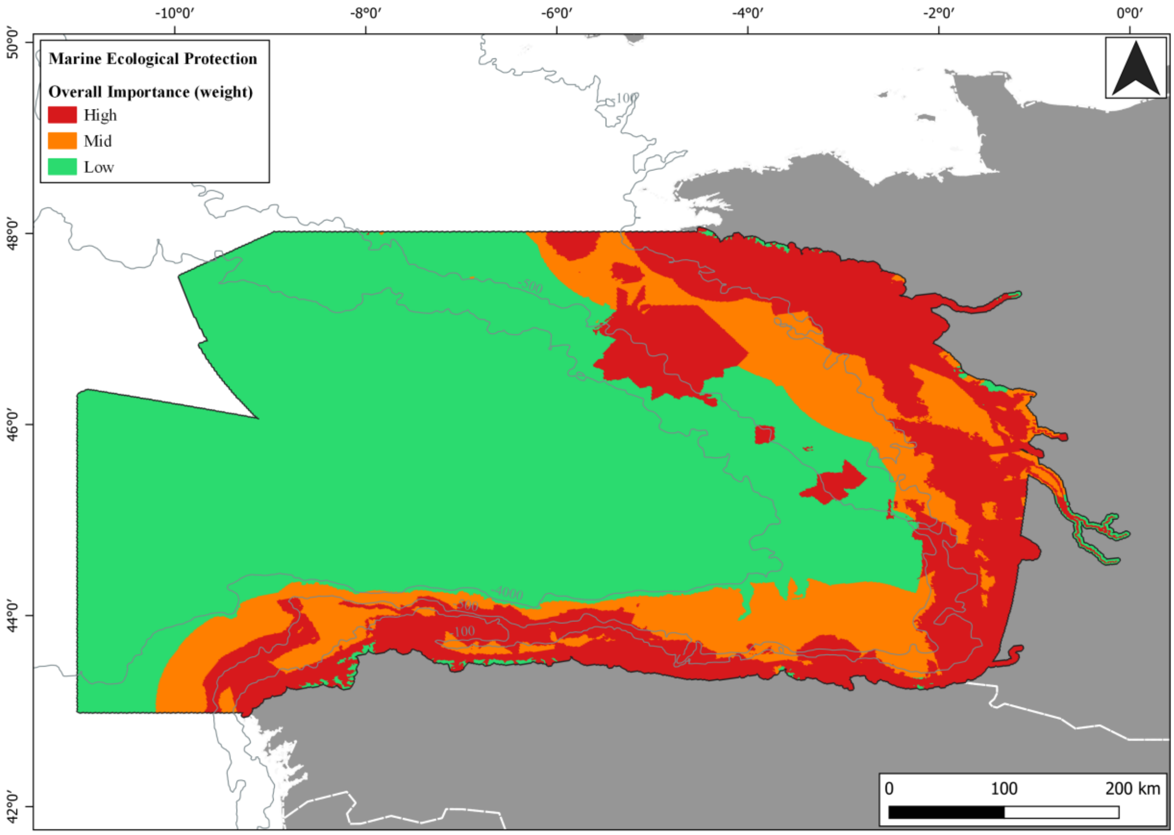

Figure 31. Marine ecological protection in the Bay of Biscay estimated with weighting factors.

On the other hand, weights can be applied also to human activities, giving more weight to those able to increase the risk for the ecosystem components, due to pressures (Halpern et al., 2015; Stelzenmüller et al., 2018). In this case, ICES (2016) identified for the Bay of Biscay the pressures produced by the activities investigated in our study. From that report, we have extracted the number of pressures by activity, as well as their intensity (value 1 for low intensity, 2 for mid and 3 for high). Then, for each activity, we have multiplied the number of pressures by its intensity, and we have obtained the 'pressure *vs.* intensity' score: 6 for fishing, 5 for aquaculture, 4 for tourism, 3 for ports and shipping, and 2 for dredging, energy and military activities. MPAs have not been weighted, since we are looking here for risk coming from activities producing pressures.

To estimate the value of each weighted human activity per grid cell, the 'pressure *vs.* intensity' scores have been multiplied by the activity's numeric importance (3 for 'High' importance, 2 for 'Mid' importance and 1 for 'Low' importance), as obtained for this report (see Figures 13 to 23). A single value of weighted human activity importance was obtained by summing up weighted importance of each human activity. This numeric value has been categorized using the percentiles 33rd and 67th (1/3 and 2/3) as "High Importance" (>2/3), "Mid Importance" (>1/3 and ≤2/3) and "Low Importance" (≤1/3) (Figure 32).

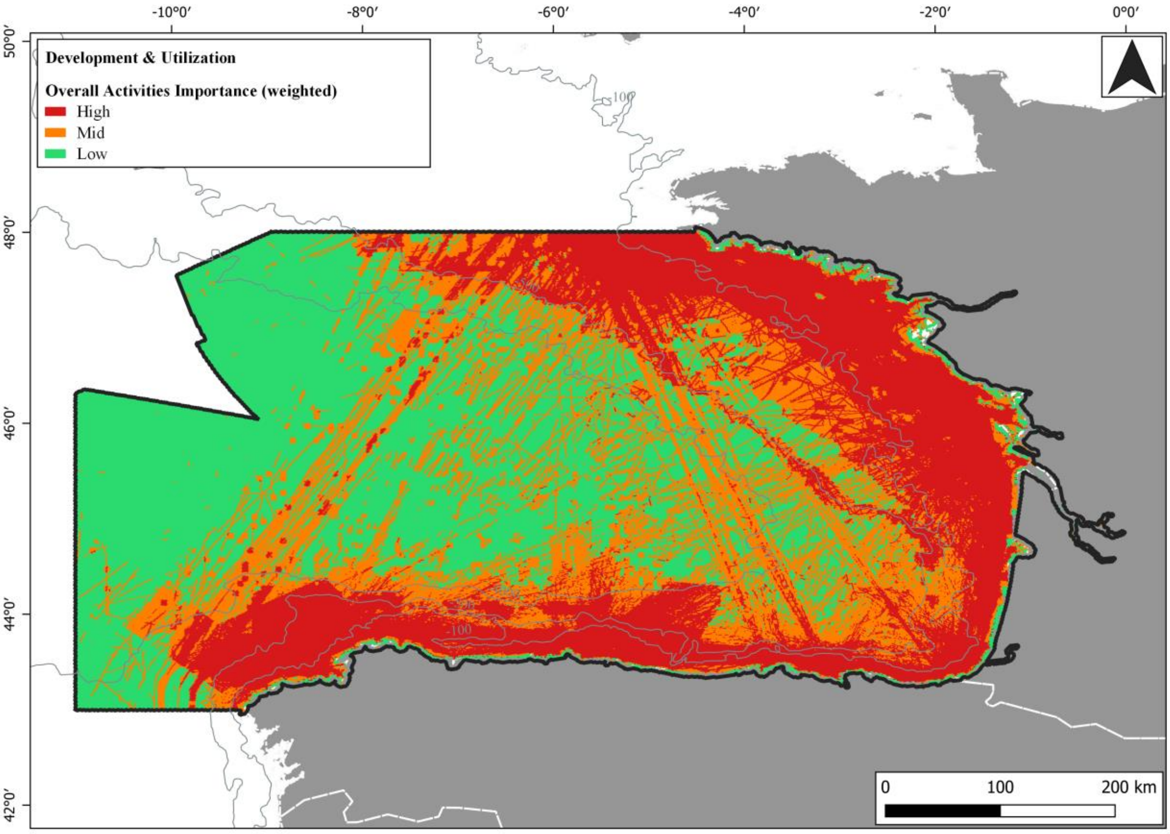

Figure 32. Importance of human activities: aggregated assessment of eight activities with weighting factors.

After having the weighted values for MEP and human activities, they have been crossed to obtain the risk values (Figure 33), and following the same methodology applied to not-weighted values. A total of 71,490 km^2 are categorized as High-risk areas, which implies an increase of 6,631 km^2, compared to the original non-weighted risk values (Table 15).

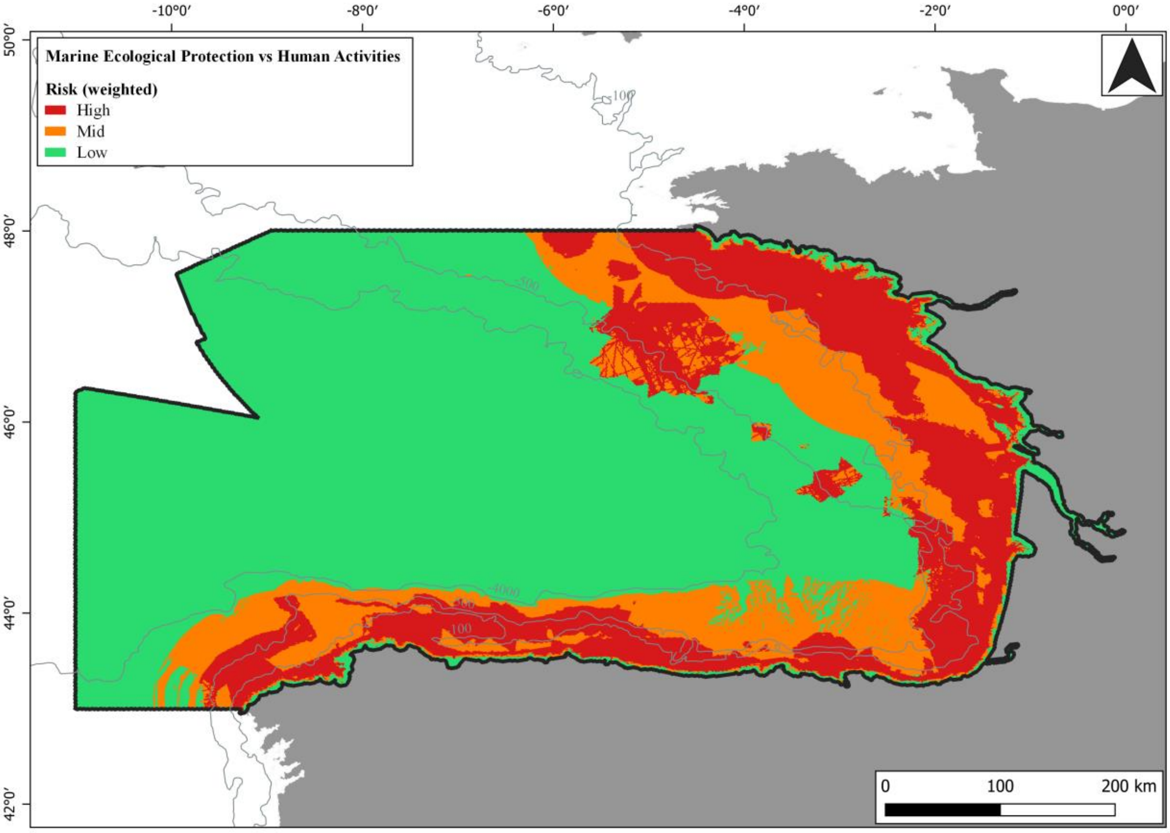

Figure 33. Risk identification with weighting factors.

Table 15. Comparison of original non-weighted values vs. weighted values for Marine Ecological Protection, Aggregated Human Activities (excluding protected areas), Risk and Marine Resource-Environment Carrying Capacity (in km² and percentage of case study). In grey colour those cells with higher values when weighting vs. non-weighted.

		Non-weighted		Weighted	
Type	Importance	km²	%	km²	%
Marine Ecological Protection	High	81,759	22.4	84,557	23.2
	Mid	61,838	17.0	59,177	16.2
	Low	221,041	60.6	220,904	60.6
Human Activities – Aggregated	High	93,844	25.7	110,062	30.2
	Mid	97,285	26.7	99,309	27.2
	Low	163,991	45.0	145,749	40.0
	Not present	9,518	2.6	9,518	2.6
Risk	High	64,859	17.8	71,490	19.6
	Mid	61,603	16.9	60,569	16.6
	Low	238,176	65.3	232,579	63.8
Marine Resource-Environment Carrying Capacity (MRECC)	-	229,266	62.9	228,637	62.7

Applying weighted values to estimate MEP importance and Human Activities' importance translates into changes for MRECC values (Figure 34). Indeed, even if the application of weighting factors does not affect to the protected areas (i.e., MPAs), it changes the areas classified as 'High' MEP importance. Therefore, the increase in the areas classified as 'High' MEP importance (from 81,759 km^2 to 84,557 km^2) means that the MRECC is slightly reduced from the 229,266 km^2 (62.9% of case study) to 228,637 km^2 (62.7%) (Table 15).

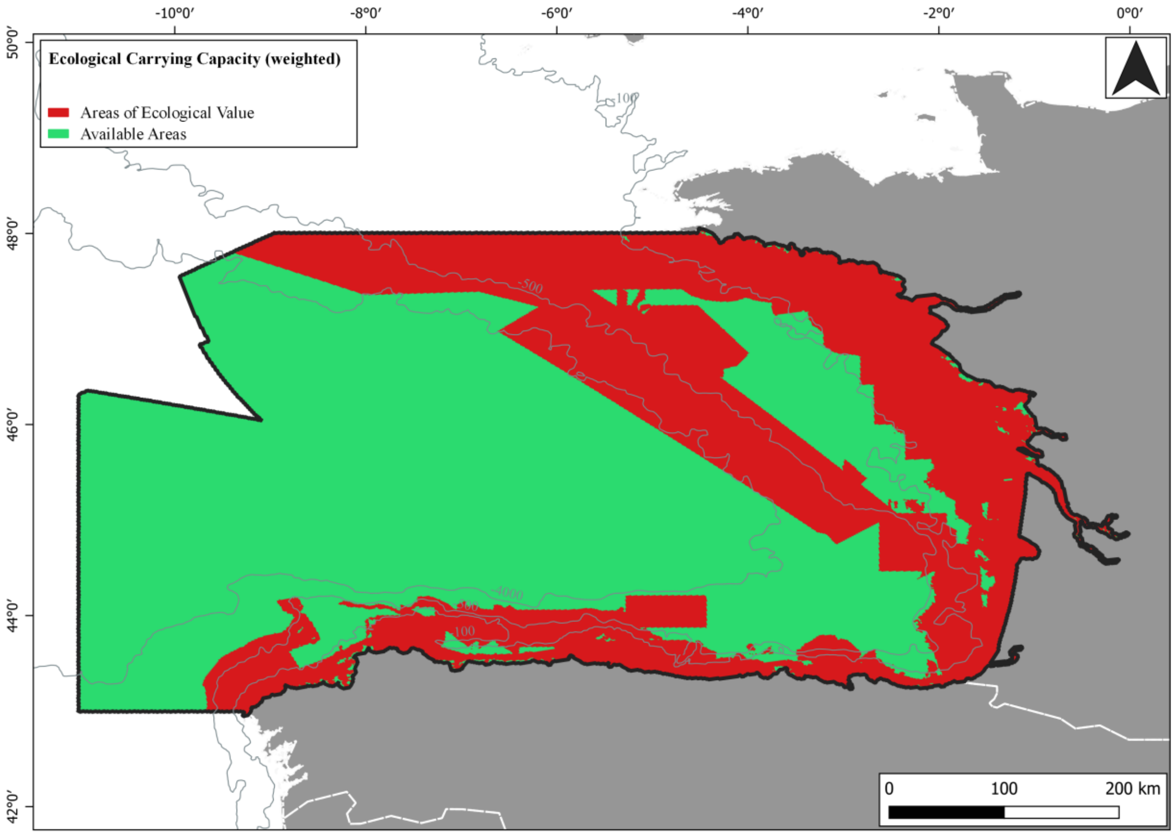

Figure 34. Marine Resource-Environment Carrying Capacity (in green) within the Bay of Biscay weighting factors.

Hence, weighting MEP and human activities results in an increase of areas at risk (until 20% of the Bay of Biscay) and a decrease in the MRECC available. Although the changes are not very important, it seems that weighting could be more adequate to determine the risk and MRECC, since this represents a precautionary principle (O'Riordan and Jordan, 1995). In fact, this is in line with other methods to assess and manage the marine systems, in which weighting factors produce more accurate results when assessing the environmental status of marine ecosystems (Borja et al., 2019b).

5 Conclusions

The double evaluation methodology developed in China was not possible to be applied directly to the European reality. It was necessary to adapt it to the current policy needs (e.g., MSPD and MSFD), especially regarding the terminology used and the human activities and ecosystem components (species, habitats, etc.), included in the analysis. After that adaptation, the application to the case study of the Bay of Biscay was possible, despite the lack of some detailed information (e.g. distribution of some species and habitats of interest), making it a challenge. Also, the availability of detailed data for site selection of human activities (e.g., aquaculture, port development, renewable energies, etc.), make difficult to determine the suitable areas for those activities, being substituted by the current areas of human activities. The most time consuming in the application of the methodology was the collection of all necessary information; however, the integration and intersection of the information (activities vs. ecological areas of interest) was simple. It seems that weighting both types of information, the results are more accurate. Applying this methodology to other areas in Europe, with different levels of data available, could facilitate the intercomparison and applicability of the approach. Besides, adaptive management approaches should also be included when applying double evaluation to MSPD in Europe, since some assumptions are different and can prevent to determine the activities to be undertaken at each space and time scales, as well as the interactions among the different activities and these and the ecosystem components in the same area and season of the year. To facilitate the application of the method, Annex 4 includes some guidelines.

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7 Annexes

7.1 Annex 1: Technical guidance on evaluation of Marine Resource-Environment Carrying Capacity and Spatial Development Suitability (official version)

(Official document provided by the China Partner (CEMDnet) and translated by the EMOD-PACE Project Coordination Office and Scientific Coordinator)

1. Scope

This technical guideline specifies the objectives, technical processes, indicator systems, and evaluation methods in evaluating Marine Resource-Environment Carrying Capacity and Spatial Development Suitability. It is applicable to the preparatory research work of marine spatial planning. This standard is region specific, meaning that different regions can refine and add relevant requirements and contents given specific local conditions to make evaluation targeted and practical.

2. Terms and definitions

2.1 Marine Resource-Environment Carrying Capacity

Marine Resource-Environment Carrying Capacity refers to the maximum and feasible volume of marine exploitation activities which can be supported by marine resources and environment in a given sea areas, which is associated with (based on) levels of development, economy and technology, production and lifestyle and goals for ecological protection.

2.2 Suitability for Marine Spatial Development

Suitability for Marine Spatial Development refers to level of suitability for exploitation activities (e.g. marine aquaculture, port construction, offshore wind power development, offshore oil and gas development) in a given ocean space, with the premise of national security and maintaining marine ecosystem health.

3. Evaluation aims

The evaluation aims are to:

- Analyse regional conditions on marine resource and environment;
- Identify and investigate problems and risks in development and utilization of marine space
- Identify key areas for marine ecological protection (including ecosystem service function areas, ecologically vulnerable areas)
- Clarify resource and environmental carrying capacity and suitable space for marine development and utilization
- Define and identify environmental limits for sustainable development
- Establish basic rules for marine spatial planning, optimizing the marine sector strategy (e.g. development and protection patterns) and regional positioning of main functions, and delineation of marine ecological protection red line areas, etc.

4. Methods for implementation aspect

4.1 Data collection

It is important to collect accurate, complete, relevant and timely data. With regard to marine resource and spatial planning, essential data include marine environmental data (i.e. geography, marine space resources, marine environment, marine ecology, marine disasters, climate and meteorology), as well as status of marine development and utilization, coastal socioeconomics, marine spatial planning and zoning, etc.

4.2 Evaluation of marine ecological protection

The evaluation of marine ecological protection includes assessment to ecosystem services and ecological sensitivity of marine ecosystem. Ecosystem service is assessed by levels of maintenance of marine biodiversity and coastal protection. The sensitivity of marine ecosystem is evaluated based on vulnerability of coastal erosion and sand loss. As a first step, the above factors will be evaluated individually, amongst which the highest level of importance is identified as the regional ecological importance level; secondly, important/highly important ecological functional areas are identified.

4.2.1 Marine biodiversity maintenance areas

The maintenance function of marine biodiversity is evaluated at three levels: species, ecosystem and genetics. The evaluation is carried out following three steps:

(1) Identify regional patches through field surveys, remote sensing, and topographical and oceanographic features;

(2) Determine the specific evaluation indicators and identify the importance of each patch considering the main ecological functions of various regions;

(3) The highest grade of each patch is the evaluation result of the maintenance function of marine biodiversity.

Table 1 Classification system of marine biodiversity maintenance function

Level	Area	Identification and delineation method	Specific indicators	Areas of high importance	Areas of importance
Species Level	Species distribution area	Carry out field survey or refer to relevant protected areas to identify targeted areas of species distribution, breeding, migratory, living	Population size	Endangered / critical	Vulnerable
			Importance of distribution area	Centralized distribution area / breeding area	Migratory area
Ecosystem level	Coral reef	Remote sensing and field investigation	Habitat area and coverage	Identify as high-importance	
	Mangrove	Remote sensing interpretation and field investigation	Habitat area and coverage	Identify as high-importance	
	Seagrass bed	Remote sensing and field investigation	Habitat area and coverage	Identify as high-importance	
	Seaweed habitat	Field investigation	Habitat area	<50th percentile	>50th percentile
			Primary productivity or chlorophyll	High	Medium and low
			Biodiversity (fish, mammals, etc.)	High	Medium and low
	Coastal marsh	Remote sensing and field investigation	Habitat area	<50th percentile	>50th percentile
			Life history (i.e. migration and habitat of birds)	Importance	Average
			Vegetation coverage	High	Medium and low
	Tidal flats and shallow waters	Tidal flat refers to the area that is above water level at low tide and underwater at high tide; shallow water refers to areas from high	Habitat area	<50th percentile	>50th percentile
			Diversity of benthos	High	Medium and low

Level	Area	Identification and delineation method	Specific indicators	Areas of high importance	Areas of importance
		tide to -6m isobath.	Life history (i.e. migration and habitat of birds)	Important	Average

Level	Area	Identification and delineation method	Specific indicators	Areas of high importance	Areas of importance
	Estuary	Remote sensing, landscape, water depth	Primary productivity or Chlorophyll	High	Medium and low
			Diversity (Swimming species)	High	Medium and low
			Life history (Mainly migration and inhabitation for birds, spawning and migration for fish)	High importance	Average
	Island	Remote sensing to identify islands, based on which the area is extended along 6m water depth; islands distributed in a concentrated manner can be grouped	Life history (Mainly for the migration and habitat of birds)	High importance	Average
			Diversity (Mainly for species only occur on the island and fishery resources in adjacent area)	High	Medium and low
			Vegetation coverage	>75%	<75%
			Importance of rights	Islands within the territorial sea baseline	—
	Fishery resources growing area	Field survey or refer to relevant protected areas	Importance of life history (fishery resources)	Spawning ground	Important fishing ground, Wintering field, Migratory channels, etc.
			Population importance	Key species,	Common species
	Other unique habitats	Other areas with unique and rare populations, ecosystems, topography, landforms or oceanographic characteristics, are decided onsite or by physical geographic boundaries, oceanographic characteristics (such as upwelling).	Unique	High	Medium and low
			Diversity	High	Medium and low
Genetic level	Aquatic genetic resources	Field survey or determination with reference to aquatic germplasm resource protection areas	Importance of area	Important (such as nature reserve, core area)	Average

4.2.2 Importance of coastal protection function

The relative importance of the coastal protection function is assessed by identifying biological protection areas (i.e. coastal forests, mangroves, salt marshes), and physical protection areas (i.e. Bedrock coast, sandy shore).

Table 2 Classification system of coastal protection function.

Area		Identification and delineation method	Specific indicators	Areas of high-importance	Areas of importance
Biological protection area	Mangroves, salt marshes, coastal forests (shelterbelts)	Remote sensing and field survey to identify distribution areas of mangroves, salt marshes and coastal forests	Habitat area, vegetation coverage, belt width of coastal forests	Concentrated patch, high vegetation coverage, large width	Others
Physical protection area	Bedrock coast	The distance from coastline to the land ranges up to 100 meters	Shore length	Large scale and un-interrupted; >1km	Other

	Sandy shore	The distance from coastline to land and delineated towards sea by geographical boundaries	Shore length, width, slope	gently sloping, large scale, un-interrupted and quite flat	Other

4.2.3 Assessment of coastal vulnerability: coastal erosion and sand loss

Coastal erosion and sand loss are assessed via parameters such as coastal sediment types and storm surge and erosion rate, as well as identification of vulnerable natural coast and restored sandy/silty/muddy coasts. Area is defined by geographic boundary from shoreline to land.

Coastal erosion vulnerability is calculated as (N+M)/2, in which N is Natural factors of coastal erosion and M is the dynamic factor of coastal erosion.

N=(g×a1+h×a2+Hw×a3)/3, in which g is Coastal sediment type, h is water-level rise cause by storm surge, Hw is average wave height, M is Coastal erosion rate and a is weighting factor (please refer to below table3 a1, a2, and a3 are valued at 0.5, 0.4 and 0.1 respectively). Areas with calculated scores 3.5-5, 1.5-3.5 and <1.5 are identified as very vulnerable, vulnerable and average respectively.

Table 3 Parameters for assessment of classification and evaluation of coastal erosion vulnerability

Parameters		**Scores for different types**		
		5	**3**	**1**
Types		Sandy/silty/muddy coasts	Natural shorelines with ecological functions	Artificial shorelines/bedrock shores
Water-level increase by storm surge (m)		≥3.0	1.5~3.0	<1.5
Average wave height (m)		≥1.0	0.4~1.0	<0.4
Erosion rate m/a	Silty/muddy coast	≥10	1-10	<1
	Sandy coast	≥2.0	0.5-2	<0.5

4.3 Suitable marine development and utilization

Suitability of marine development and utilization is assessed via marine development and utilization functions, considering the potential of marine resources and the status of development and utilization. Individual elements (e.g. sea resources, environment, ecology, location, etc.) are evaluated as a first step. Secondly, the individual elements are integrate. Suitability of marine development and utilization is classified into five levels: suitable, more suitable, generally suitable, less suitable and unsuitable.

4.3.1 Suitability for marine aquaculture

Step 1: Individual evaluation index is selected based on factors such as regional topographical features, hydrodynamic conditions, environmental conditions, biological resources, and natural disaster risk, specific breeding varieties and breeding methods.

(1) Marine environment

Seawater quality indicator reflects the limiting effect of seawater environment on aquaculture.

Seawater quality is classified into 5 levels according to the "Seawater Quality Standards" (GB3097-1997), "Technical Regulations for Evaluation of Seawater Quality" (Trial) (Haihuanzi [2015] No. 25): 1st, 2nd, 3rd, 4th class and worse than 4th class. Factors analysed for the assessment include regional seawater quality monitoring data, regional pollution problems, pH, chemical oxygen demand, dissolved oxygen, petroleum and heavy metals (except for inorganic nitrogen, phosphate, silicate and other nutrients).

The suitability for marine aquaculture is classified into five grades: good, better, fair, poor, and poor.

(2) Marine disasters

Impact of marine disasters on marine aquaculture activities is evaluated by indexing risks of sea wave, sea ice and red tide disasters. Assessments to wave disaster risk is performed by referring to "Sea Wave Disaster Risk

Assessment and Zoning Technical Guidelines" and historical wave data. It is quantified as wave disaster risk index based on the effective wave height during the typical recurrence period and classified into very low, low, medium, high and very high.

(3) Marine resources and physical/chemical conditions

The conditions are classified into three grades (i.e. high, medium and low) based on specific breeding species and breeding methods, water depth, bottom sediment types (i.e. bedrock, gravel, sand, mud, etc.), flow velocity, water temperature, salinity and biological resource conditions of marine aquaculture.

Step 2: Integrated evaluation

Integration of individual evaluation to develop a comprehensive marine aquaculture suitability grading system.

(1) Integrated evaluation of marine disasters

The highest grade evaluated from wave disaster, sea ice disaster and red tide disaster is identified as the integrated index of marine disasters. The risks are classified into five grades: very low, low, medium, high and very high.

(2) Integrated evaluation of marine resources and physical/chemical conditions

The various marine resources and physical and chemical conditions are integrated by discriminant matrix method according to the requirements of marine aquaculture. The conditions are divided into three levels: high, medium and low.

(3) Comprehensive evaluation of suitability

The suitability level for marine aquaculture is finally decided based on the results of integrated evaluation of marine disasters and integrated evaluation of marine resources and physical/chemical conditions:

The suitability level is reduced to a lower grade in an area with high/very high risk of marine disasters, and the suitability level is identified to low in an area with seawater environmental conditions worse than 2nd class.

4.3.2 Suitability for port construction

Step 1: Individual evaluation

Evaluation of the suitability for port construction activities is based on appropriate individual evaluation index. These indexes are decided by factors such as regional spatial resources, hydrodynamic conditions and natural disaster risks.

(1) Evaluation of onshore area

Onshore area move towards land (~2km) from the shoreline, conditions of which are characterized by slope and relief height. Slope is calculated from digital elevation models and a slope map is created by categorizing slopes into ≤3°,3~8°,8~15°,15~25° and >25°.

Revision of the categorization according to relief height: in an area with relief height >200m, the grade decreases two levels; in an area with relief height between 100m and 200m, the grade decreases one level.

The averaged value is calculated within 2km region applying neighbourhood tool and categorised into five grades: very high (≥ 5), high (4 ~ 5), medium (3 ~ 4), low (2 ~ 3), and very low (< 2).

(2) Evaluation of bottom conditions

The impact of port construction is categorized into three levels based on sediment types: bedrock (good), silty/muddy shoreline (medium) and sandy shoreline (bad).

(3) Evaluation of water depth

According to the standards for the deep water coastline of a port, formulated by the administrative department of communications under the State Council, the conditions of water depth are divided into 5 levels dependent on the distances from 10m isobaths: ≤1.5km (Good), 1.5~3km (above average), 3~4.5km (average), 4.5~6km (below average), >6km (bad).

(4) Assessment to risks of marine disasters

The risks of marine disasters are categorized into four levels (i.e. very low, low, high, very high) with reference to Guideline for risk assessment and zoning of storm surge disaster. Annual average risk index of storm surge disasters at each tide (water) station is determined by factors such as water level increase caused by storm surge and storm alert.

(5) Water width

Water width is considered in the areas with narrow waterways and islands dependent on the distance to shoreline >600m (good), 300-600m (medium), <300m (bad).

(6) Evaluation of transportation infrastructure

The condition for port construction is characterized by public transport accessibility from main roads and transportation hubs. Public transport accessibility from the main roads is analysed by distances between grid cells and roads/railways and categorized into five levels: very good, good, average, bad, very bad. Public transport accessibility from transportation hubs is dependent on the travel time from grid cells to transportation hubs and categorized into five levels: very good, good, average, bad, very bad.

Step 2: Integrated valuation

(1) Integration of shoreline bottom type and water depth is used to evaluate conditions of shoreline resource utilization with reference to the discriminant matrix table below. The conditions are classified into 5 levels: very high, high, medium, low and very low.

Table 4 Discriminant matrix.

Conditions of water depth	Conditions of sediment types		
	Good	Medium	Bad
Good	Very High	High	Medium
Above average	High	Medium	Low
Average	Medium	Low	Very Low
Below average	Low	Very Low	Very Low
Bad	Very Low	Very Low	Very Low

The evaluation result is adjusted based on onshore area and water width. For areas with onshore area grades “very low” and “low”, the final grades are reduced two levels and one level as the final results, respectively. For area with water width grade “very low”, the final grade is reduced one level.

(1) Suitability for port construction

Initial evaluation is performed based on grade results of shoreline resource utilization and risk of marine disasters. It is further adjusted to grade “medium” for areas with shoreline resource utilization evaluated as “high” and “very high”. For areas whose shoreline resource utilization evaluated as “very high” and risk of marine disaster evaluated as “high”, the final grade is adjusted to “high”.

Final evaluation is done by integrating transportation infrastructure grade, i.e. port construction suitability grade is adjusted to “very low” and reduced one level in areas with transportation infrastructure evaluated as “very bad” and “bad” respectively.

4.3.3 Suitability for Development and Construction of Offshore Wind Power

Step 1: Individual evaluation

(1) Evaluation of wind energy potential

Wind energy potential is evaluated by wind power density at 100m height and classified into five grades i.e. very high, high, medium, low, very low correspondent to ≥450W/m^2,400-450 W/m^2, 350-400 W/m^2,300-350 W/m^2,<300 W/m^2.

Step 2: Integrated evaluation on suitability for development and construction of offshore wind power

(1) Suitability is categorized into 5 levels in accordance with evaluation of wind energy potential, i.e. very high, high, medium, low, very low.

(2) Adjustment made to the integrated evaluation based on offshore distance and water depth. With reference to Measures for the Administration of the Development and Construction of Offshore Wind Power (No. 394 [2016] of the National Energy Administration), suitability is adjusted to “very low” for areas with offshore distance <10km and reduced one level in areas with water depth >50m where offshore wind power is difficult to be developed and constructed.

4.3.4 Offshore oil and gas development suitability

Step 1: Individual evaluation

(1) Evaluation of oil and gas resources

Area resource abundance index (i.e. the amount of oil and gas resources per evaluation area or scale area) is to evaluate suitability of offshore oil and gas development considering geological resources.

Table 5 Grading system of oil and gas resource abundance.

Level	Oil resource abundance per area（10^4t/km^2）	Gas resource abundance per area（$10^8 m^3/km^2$）
Very High	> 30	>3
High	20 ~ 30	2 ~ 3
Medium	10 ~ 20	1 ~ 2
Low	5 ~ 10	0.5 ~ 1
Very Low	< 5	< 0.5

Step 2: Integrated evaluation

(1) Initial evaluation of the suitability for offshore oil and gas development is categorized into very high, high, medium, low, very low in accordance with area resource abundance index.

Table 6 Threshold of patch configuration.

Patch configuration	Very Low	Low	Average	High	Very High
Oil patch（km^2）	<3.0	3.0-4.5	4.5-9.0	9.0-18.0	≥18.0
Gas patch（km^2）	<1.0	1.0-2.0	2.0-4.0	4.0-8.0	≥8.0

Adjustment is made by integrating patch configuration with reference to Discriminant matrix for modifying offshore oil and gas development suitability. In areas with suitability graded as “low” or “very low”, no adjustment is needed.

Table 7 Discriminant matrix for modifying offshore oil and gas development suitability.

Grades of offshore oil and gas development suitability	Patch configuration				
	Very high	High	Medium	Low	Very low
Very high	Very high	High	High	High	High
High	High	High	Medium	Medium	Medium
Medium	Medium	Medium	Medium	Medium	Medium

4.4 Environmental analysis of resource endowment

Advantages and constraints of the resource environment is summarized by combining analysis of marine environment, biodiversity, ecology, mineral resource (e.g. quantify, quality, structure, distribution and trend), climate, disaster, etc.

4.5 Risk identification

Environmental problems caused by overexploitation of resources are identified by comprehensively analysing the status of development and utilization of marine resources (e.g. scale, structure, layout, quality, efficiency, benefits and changes). Therefore, future trends can be predicted and risks can be assessed based on the identified environmental problems.

4.6 Evaluation of carrying capacity

Ecological carrying capacity is estimated as the maximum capacity of development and utilization of marine resources to ensure sustainable development of coastal area. The maximum carrying capacity is estimated by excluding marine ecological protection areas with level “high importance” and areas not suitable for marine development and utilization activities.

4.7 Potential analysis

With reference to the evaluation results of suitability and ecological carrying capacity, the following situations can be assessed:

- Zonation of suitability classification
- Status of marine resource exploitation
- Identity activities carried out in areas not suitable for development
- Potential risks

In the meantime, potential analysis provides scientific support to optimize marine spatial planning and resource utilization by analysing the status of current planning/strategy and future needs for marine development.

7.2 Annex 2: Technical guidance on evaluation of Marine Resource-Environment Carrying Capacity and Spatial Development Suitability (adapted version)

(Adapted version from the official document translated in Annex 1)

1. Scope

This technical guideline specifies the objectives, technical processes, indicator systems, and assessment methods in evaluating Marine Resource and Environmental Carrying Capacity and Spatial Development Suitability. It is applicable to the preparatory research work for marine spatial planning (MSP). This standard is region specific, meaning that different regions can refine, add relevant requirements and contents given specific local conditions to make evaluation targeted and practical.

2. Terms and definitions

2.1. Marine Resource-Environment Carrying Capacity

"Environmental Carrying Capacity" (ECC) refers to the maximum and feasible volume of marine human activities[43] which can be supported by marine resources and environment in a given sea area, which is associated with (based on) levels of development, economy and technology, production and lifestyle and goals for ecological protection[44].

2.2. Suitability for maritime activities[45]

Suitability for maritime activities refers to the level of human activities at sea (e.g. marine aquaculture, port construction, offshore wind power development, offshore oil and gas development), in a given ocean space, with the premise of national security and maintaining marine ecosystem health[46].

3. Evaluation aims

The evaluation aims are to:

- Analyse regional conditions of marine resources[47] and environment.
- Identify and investigate problems and risks in development[48] and utilization of marine space.
- Identify key features and areas for protection (including ecosystem service provisioning areas and vulnerable areas).
- Clarify resource and environmental carrying capacity and suitable space for maritime activities development.
- identify and define environmental limits for sustainable development.
- Establish basic rules for MSP implementation by optimizing the marine sectors objectives (both

[43] In the official document referred to as 'exploitation activities', adapted to the European terminology, such as that in the Marine Strategy Framework Directive (MSFD).

[44] Hence, in European terminology, the amount of activities that can be undertaken in an area, in a sustainable way, without compromising to achieve Good Environmental Status (GES), after the MSFD.

[45] In the official document referred to as 'Marine Spatial Development', adapted to the European terminology, such as that in the MSFD or the Maritime Spatial Planning Directive (MSPD), as well as in the Blue Growth Strategy.

[46] In European terminology, to achieve or maintain GES, after the MSFD.

[47] Either biotic (i.e. fish, crustaceans, etc.) or abiotic (i.e. wind energy, wave energy, etc.)

[48] Equivalent to the ecological risk assessment, in Europe

considering their performance and development, together with ecological protection and conservation) and regional positioning of main functions, and delineation of marine ecological protection red line areas, etc.[49]

4. Methods to implement the MRECC

4.1. Data collection

It is important to collect accurate, complete, relevant, and timely data. With regard to marine resources and spatial planning, essential data include marine environmental data (i.e. geography, marine space distribution of the resources, marine environment, marine ecology, marine disasters, climate and meteorology), as well as status of marine development and utilization, coastal socioeconomics, marine spatial planning and zoning, etc.[50]

4.2. Evaluation of marine ecological protection

The evaluation of marine ecological protection includes the assessment to ecosystem services and the ecological sensitivity of marine ecosystem. Ecosystem services are assessed by levels of maintenance of marine biodiversity and coastal protection[51]. The sensitivity of marine ecosystem is evaluated based on vulnerability to coastal erosion and sand loss[52]. As a first step, the above factors will be evaluated individually, amongst which the highest level of importance is identified as the regional ecological importance level; secondly, important/highly relevant ecological functional areas are identified.

4.2.1 Marine biodiversity maintenance areas

The maintenance function of marine biodiversity is evaluated at three levels: species, habitat[53], and genes[54]. The evaluation is carried out following three steps (Table 1):

(4) Identify the spatial distribution of habitats[55] through field surveys, remote sensing, and topographical and oceanographic features;

(5) Determine the specific evaluation indicators and identify the importance of each habitat considering the main ecological functions;

(6) The highest grade of each habitat area is the evaluation result of the marine biodiversity maintenance function.

Table 1. Classification system of marine biodiversity maintenance function.

Level	Area	Identification and delineation method	Specific indicators	Areas of high importance	Areas of importance
Species Level	Species[56] distribution area	Field survey or relevant protected areas to identify targeted areas of species distribution, breeding, migratory, living	Population size	Endangered / critical	Vulnerable
			Importance of distribution area	Centralized distribution area / breeding area	Migratory area

[49] In European terminology, this means to achieve or maintain GES (after the MSFD) while at the same time allowing sustainable maritime activities (MSPD). This is, making compatible MSFD and MSPD.

[50] In European terminology, this should include biotic (habitats, species, etc.) and abiotic (hydrography, climate, etc.) information, as well as uses, planning (including marine protected areas), environmental status (from MSFD or Regional Seas Conventions), ecosystem services mapping and assessment, etc.

[51] In addition to those proposed in this official method, all ecosystem services types should be considered (provisioning, regulating and cultural). They must be spatially explicit and at the highest spatial resolution.

[52] But we will need to also add vulnerability to biological (including habitats, biodiversity) loss.

[53] In the official version 'habitats' are 'ecosystems', but in European terminology, they refer to habitats. Changed throughout the text.

[54] In the official version is 'genetics', I think that 'genes' is more correct.

[55] In the official version is 'regional patches', but it should be considered as 'habitat distribution areas'

[56] Here, those threatened species which are vulnerable, endangered, or critically endangered according to IUCN red list are considered. However, we can consider those species under Descriptor 1 (biodiversity) within the MSFD.

Habitat Level[57]	Seagrass bed	Remote sensing and field investigation	Habitat area and coverage	Identify as high-importance	
	Seaweed habitat	Field investigation	Habitat area	<50th percentile[58]	>50th percentile
			Primary productivity or chlorophyll	High	Medium and low
			Biodiversity (fish, mammals, etc.)	High	Medium and low
	Coastal marsh	Remote sensing and field investigation	Habitat area	<50th percentile	>50th percentile
			Life history (i.e. migration and habitat of birds)	Importance	Average
			Vegetation coverage	High	Medium and low
	Tidal flats and shallow waters[59]	Tidal flat refers to the area that is above water level at low tide and underwater at high tide; shallow water refers to areas from high tide to -6 m isobath	Habitat area	<50th percentile	>50th percentile
			Diversity of benthos	High	Medium and low
			Life history (i.e. migration and habitat of birds)	Important	Average
	Estuary	Remote sensing, landscape, water depth	Primary productivity or Chlorophyll	High	Medium and low
			Diversity (swimming species)	High	Medium and low
			Life history (mainly migration and inhabitation for birds, spawning and migration for fish)	High importance	Average
	Island	Remote sensing to identify islands, based on which the area is extended along 6m water depth; islands distributed in a concentrated manner can be grouped	Life history (mainly for the migration and habitat of birds)	High importance	Average
			Diversity (mainly for species only occur on the island and fishery resources in adjacent area)	High	Medium and low
			Vegetation coverage	>75%	<75%
			Importance of rights	Islands within the territorial sea	
	Fishery growing area	Field survey or relevant protected areas	Importance of life history (fishery resources)	Spawning ground	Important fishing ground, wintering field, migratory channels, etc.
			Population importance	Key species	Common species
	Other unique habitats	Other areas with unique and rare populations, topography, landforms or oceanographic characteristics, are decided onsite or by physical geographic boundaries, oceanographic characteristics (such as upwelling)	Unique	High	Medium and low
			Diversity	High	Medium and low
Genes level	Aquatic genetic resources	Field survey or determination with reference to aquatic germplasm resource protection areas.	Importance of area	Important (such as nature reserve, core area)	Average

4.2.2. Importance of coastal protection function

The relative importance of the coastal protection function is assessed by identifying biological protection areas

[57] Here, we can consider some criteria in D1 and D6 (seafloor integrity), from the MSFD
[58] Areas with the habitat extent of top 50% in China are determined to be of high importance.
[59] In China this includes both tidal flats and shallow waters, which are no deeper than 6 m, based on the definition in Ramsar Wetland.

(i.e. coastal forests, salt marshes), and physical protection areas (i.e. bedrock coast, sandy shores) (Table 2).

Table 2. Classification system of coastal protection function.[60]

Area		Identification and delineation method	Specific indicators	Areas of high-importance	Areas of importance
Biological protection area	Salt marshes, coastal forests, etc. (shelterbelts)	Remote sensing and field survey to identify distribution areas of mangroves, salt marshes and coastal forests	Habitat area, vegetation coverage, belt width of coastal forests	Concentrated patch, high vegetation coverage, large width	Others
Physical protection area	Bedrock coast	The distance from coastline to the land ranges up to 100 meters	Shore length	Large scale and un-interrupted; >1 km	Other
	Sandy shore	The distance from coastline to land and delineated towards sea by geographical boundaries [61]	Shore length, width, slope	Gently sloping, large scale, un-interrupted and quite flat	Other

4.2.3. Assessment of coastal vulnerability: coastal erosion and sand loss

Coastal erosion and sand loss are assessed via parameters such as coastal sediment types, storm surge and erosion rate, as well as identification of vulnerable natural coast and restored sandy/silty/muddy coasts. Area is defined by geographic boundary from shoreline to land.

Coastal erosion vulnerability is calculated[62] as:

$$(N+M)/2$$

in which **N** is Natural factors of coastal erosion and **M** is the dynamic factor of coastal erosion, being:

$$N= (g\times a1 + h\times a2 + Hw\times a3)/3$$

in which **g** is Coastal sediment type, **h** is water-level rise caused by storm surge, **Hw** is average wave height, **M** is Coastal erosion rate and **a** is weighting factor (refer to Table 3, a1, a2, and a3 are valued at 0.5, 0.4 and 0.1, respectively).

Final vulnerability is:

- Scores 3.5-5: very vulnerable
- Scores 1.5-3.5: vulnerable
- Scores <1.5: less vulnerable

Table 3. Parameters for assessment of classification and evaluation of coastal erosion vulnerability (values as annual averages)[63]

Parameters		Scores for different types		
		5	3	1
Types		Sandy/silty/muddy coasts	Natural shorelines with ecological functions	Artificial shorelines/bedrock shores
Water-level increase by storm surge (m)		≥3.0	1.5~3.0	<1.5
Average wave height (m)		≥1.0	0.4~1.0	<0.4
Erosion rate (m yr^{-1})	Silty/muddy coast	≥10	1-10	<1
	Sandy coast	≥2.0	0.5-2	<0.5

60 They should be considered as ecosystem services protection. This paper can serve as guide and we can use the results from there: Liquete, C., G. Zulian, I. Delgado, A. Stips, J. Maes, 2013. Assessment of coastal protection as an ecosystem service in Europe. Ecological Indicators, 30: 205-217.

61 This is to set a physical buffer in rocky and sandy shores, generally 100 metres.

62 All data are into raster layers with the same resolution (e.g. 20 m) and do calculations between different layers.

63 We need to discuss these values, to adapt them to the Bay of Biscay/Europe

4.3. Suitable marine development and utilization

Suitability of marine development and utilization is assessed via maritime spatial planning[64], considering the potential of marine resources and the status of development and utilization[65]. Individual elements (e.g. sea resources, environment, ecology, location, etc.) are evaluated as a first step. Secondly, the individual elements are integrated. Suitability of marine development and utilization is classified into five levels: Highly suitable, Suitable, Moderately suitable, Less suitable and Unsuitable[66].

4.3.1 Suitability for marine aquaculture[67]

Step 1: An individual evaluation index is selected, based on factors such as regional topographical features[68], hydrodynamic conditions, environmental conditions, biological resources, and natural disaster risk, specific breeding varieties and breeding methods.

(1) Marine environment

Seawater quality reflects the limiting effect of seawater environment on aquaculture. It is classified into 5 levels[69] according to the Water Framework Directive (physico-chemical factors and chemical status) and the MSFD (Descriptors 5 -eutrophication-, 8 -contaminants in the environment- and 9 -contaminants in seafood-). Indicators analysed for the assessment include regional seawater quality monitoring data, regional pollution problems, pH, dissolved oxygen, and contaminants (except for inorganic nitrogen, phosphate, silicate and other nutrients).

The suitability for marine aquaculture is classified into five levels, as in the WFD: high, good, moderate, poor, and bad[70].

(2) Marine disasters

Impact of marine disasters on marine aquaculture activities is evaluated by indexing risks of sea wave, and red tides. Assessments to wave disaster risk is performed by referring to "Sea Wave Disaster Risk Assessment and Zoning Technical Guidelines" and historical wave data. It is quantified as wave disaster risk index based on the effective wave height during the typical recurrence period and classified into very low, low, medium, high and very high.

(3) Marine resources and physical/chemical conditions

The conditions are classified into three grades (i.e. high, medium and low) based on specific breeding species and breeding methods, water depth, bottom sediment types (i.e. bedrock, gravel, sand, mud, etc.), flow velocity, water temperature, salinity and biological resource conditions of marine aquaculture.

Step 2: Integrated evaluation

Integration of individual evaluation to develop a comprehensive marine aquaculture suitability grading system.

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[64] In the original document this term was 'marine development and utilization functions', which has been adapted to MSP.

[65] In the original document four activities are included: aquaculture, port development, wind farms and oil & gas exploitation. We should consider all activities, not only those.

[66] In the original document the levels were: suitable, more suitable, generally suitable, less suitable and unsuitable. They have been adapted.

[67] In the original document, they are trying to build a general framework to assess the suitability for spatial use of maritime aquaculture. More factors based on the physiological features of specific species can be considered.

[68] Some automated classification techniques, based on the gridded bathymetry (focus on the depth for specific species or sheltering conditions such as bay), can be considered.

[69] In the original document the assessment was done following "Seawater Quality Standards" (GB3097-1997), "Technical Regulations for Evaluation of Seawater Quality" (Trial) (Haihuanzi [2015] No. 25): 1st, 2nd, 3rd, 4th class and worse than 4th class". These have been adapted to the European legislation.

[70] In the original document they were, good, better, fair, poor, and poor (something was wrong), and they have been adapted to those in the WFD.

(1) Integrated evaluation of marine disasters

The highest grade evaluated from wave disaster and red tides is identified as the integrated index of marine disasters. The risks are classified into five grades: very low, low, medium, high and very high.

(2) Integrated evaluation of marine resources and physical/chemical conditions

The various marine resources and physical and chemical conditions are integrated by discriminant matrix method according to the requirements of marine aquaculture. The conditions are divided into three levels: high, medium and low.

(3) Comprehensive evaluation of suitability

The suitability level for marine aquaculture is finally decided based on the results of integrated evaluation of marine disasters and integrated evaluation of marine resources and physical/chemical conditions:

The suitability level is reduced to a lower grade in an area with high/very high risk of marine disasters, and the suitability level is identified as low in an area with seawater environmental conditions worse than 2nd class.

4.3.2. Suitability for port construction[71]

Step 1: Individual evaluation

Evaluation of the suitability for port construction activities is based on appropriate individual evaluation index. These indexes are decided by factors such as regional spatial resources, hydrodynamic conditions and natural disaster risks.

(1) Evaluation of onshore area

Onshore area moves towards land (~2 km) from the shoreline, conditions of which are characterized by slope and relief height. Slope is calculated from digital elevation models and a slope map is created by categorizing slopes into ≤3°, 3~8°, 8~15°, 15~25° and >25°.

Revision of the categorization according to relief height: in an area with relief height >200 m, the grade decreases two levels; in an area with relief height between 100 m and 200 m, the grade decreases one level.

The averaged value is calculated within 2 km region applying neighbourhood tool and categorised into five grades: very high (≥ 5), high (4 ~ 5), medium (3 ~ 4), low (2 ~ 3), and very low (< 2).

(2) Evaluation of bottom conditions

The impact of port construction is categorized into three levels based on sediment types: bedrock (no impact), silty/muddy shoreline (medium impact) and sandy shoreline (high impact)[72].

(3) Evaluation of water depth

According to the standards for the deep-water coastline[73] of a port. The conditions of water depth are divided into 5 levels depending on the distances from 10 m isobaths: ≤1.5 km (Good), 1.5~3 km (above average), 3~4.5 km (average), 4.5~6 km (below average), >6 km (bad)[74].

(4) Assessment to risks of marine disasters

The risks of marine disasters are categorized into four levels (i.e. very low, low, high, very high) with reference to Guideline for risk assessment and zoning of storm surge disaster. Annual average risk index of storm surge

[71] Maybe some parts can be taken from the ETC-ICM work done for the EEA on sustainable ports and shipping.

[72] In the original document the levels were good, medium and bad.

[73] The coastline is defined as the intersection of the topography and the lowest astronomical tide

[74] In China, the slope of the bathymetry is not taken into account, because nearly almost territorial waters are on the continental shelf, which has gentle slope. Hence, they consider the factor of distance from the coast and do not consider the slope. This can be modified.

disasters at each tide (water) station is determined by factors such as water level increase caused by storm surge and storm alert.

(5) Water width

Water width is considered in the areas with narrow waterways and islands dependent on the distance to shoreline >600 m (good), 300-600 m (medium), <300 m (bad).

(6) Evaluation of transportation infrastructure

The condition for port construction is characterized by public transport accessibility from main roads and transportation hubs. Public transport accessibility from the main roads is analysed by distances between grid cells and roads/railways and categorized into five levels: very good, good, average, bad, very bad. Public transport accessibility from transportation hubs is dependent on the travel time from grid cells to transportation hubs and categorized into five levels: very good, good, average, bad, very bad.

Step 2: Integrated valuation

(1) Integration of shoreline bottom type and water depth is used to evaluate conditions of shoreline resource utilization with reference to the discriminant matrix (Table 4). The conditions are classified into 5 levels: very high, high, medium, low and very low.

Table 4. Discriminant matrix.

Conditions of water depth	Conditions of sediment types		
	Good	Medium	Bad
Good	Very High	High	Medium
Above average	High	Medium	Low
Average	Medium	Low	Very Low
Below average	Low	Very Low	Very Low
Bad	Very Low	Very Low	Very Low

The evaluation result is adjusted based on onshore area and water width. For areas with onshore area grades “very low” and “low”, the final grades are reduced two levels and one level as the final results, respectively. For areas with water width grade “very low”, the final grade is reduced one level.

(2) Suitability for port construction

Initial evaluation is performed based on grade results of shoreline resource utilization and risk of marine disasters. It is further adjusted to grade “medium” for areas with shoreline resource utilization evaluated as “high” and “very high”. For areas where shoreline resource utilization was evaluated as “very high” and risk of marine disaster was evaluated as “high”, the final grade is adjusted to “high”.

Final evaluation is done by integrating transportation infrastructure grade, i.e. port construction suitability grade is adjusted to “very low” and reduced one level in areas with transportation infrastructure evaluated as “very bad” and “bad” respectively.

4.3.3. Suitability for Development and Construction of Offshore Wind Power[75]

Step 1: Individual evaluation

(1) Evaluation of wind energy potential

Wind energy potential is evaluated by wind power density at 100 m height and classified into five grades i.e. very high, high, medium, low, very low correspondent to ≥450 W/m^2,400-450 W/m^2, 350-400 W/m^2,300-350

[75] We should consider using the European approach.

W/m^2, and <300 W/m^2.

Step 2: Integrated evaluation on suitability for development and construction of offshore wind power

(1) Suitability is categorized into 5 levels in accordance with evaluation of wind energy potential, i.e. very high, high, medium, low, very low.

(2) Adjustment made to the integrated evaluation based on offshore distance and water depth. With reference to Measures for the Administration of the Development and Construction of Offshore Wind Power (No. 394 [2016] of the National Energy Administration), suitability is adjusted to "very low" for areas with offshore distance <10 km and reduced one level in areas with water depth >50 m where offshore wind power is difficult to be developed and constructed.

4.3.4. Offshore oil and gas development suitability

Step 1: Individual evaluation

(1) Evaluation of oil and gas resources

Area resource abundance index (i.e. the amount of oil and gas resources per evaluation area or scale area) is to evaluate suitability of offshore oil and gas development considering geological resources (Table 5).

Table 5. Grading system of oil and gas resource abundance

Level	Oil resource abundance per area ($10^4 t/km^2$)	Gas resource abundance per area ($10^8 m^3/km^2$)
Very High	> 30	>3
High	20 ~ 30	2 ~ 3
Medium	10 ~ 20	1 ~ 2
Low	5 ~ 10	0.5 ~ 1
Very Low	< 5	< 0.5

Step 2: Integrated evaluation[76]

(1) Initial evaluation of the suitability for offshore oil and gas development is categorized into very high, high, medium, low, very low in accordance with area resource abundance index (Table 6).

Table 6 Threshold of patch configuration

Patch configuration	Very Low	Low	Medium	High	Very High
Oil patch (km^2)	<3.0	3.0-4.5	4.5-9.0	9.0-18.0	≥18.0
Gas patch (km^2)	<1.0	1.0-2.0	2.0-4.0	4.0-8.0	≥8.0

Adjustment is made by integrating patch configuration with reference to Discriminant matrix for modifying offshore oil and gas development suitability (Table 7). In areas with suitability graded as "low" or "very low", no adjustment is needed.

Table 7 Discriminant matrix for modifying offshore oil and gas development suitability.

Grades of offshore oil and gas development suitability	Patch configuration				
	Very high	High	Medium	Low	Very low
Very high	Very high	High	High	High	High
High	High	High	Medium	Medium	Medium
Medium	Medium	Medium	Medium	Medium	Medium

[76] For the integration, all data are included into raster layers with same resolution, and do calculations.

4.4. Environmental analysis of resource endowment

Advantages and constraints of the resource environment is summarized by combining analysis of marine environment, biodiversity, ecology, mineral resource (e.g. quantity, quality, structure, distribution and trend), climate, disaster, etc.

4.5. Risk identification[77]

Environmental problems caused by overexploitation of resources are identified by comprehensively analysing the status of development and utilization of marine resources (e.g. scale, structure, layout, quality, efficiency, benefits and changes). Therefore, future trends can be predicted, and risks can be assessed based on the identified environmental problems.

4.6. Evaluation of carrying capacity[78]

Ecological carrying capacity is estimated as the maximum capacity of development and utilization of marine resources to ensure sustainable development of a coastal area. The maximum carrying capacity is estimated by excluding marine ecological protection areas with level "high importance" and areas not suitable for marine development and utilization activities.

4.7. Potential analysis[79]

With reference to the evaluation results of suitability and ecological carrying capacity, the following situations can be assessed:

- Zonation of suitability classification.
- Status of marine resource exploitation.
- Identity activities carried out in areas not suitable for development.
- Potential risks.

In the meantime, potential analysis provides scientific support to optimize MSP and resource utilization by analysing the status of current planning/strategy and future needs for marine development.

[77] This is undertaken by overlapping the assessment result and existing/potential maritime activities, to identify problems and risks. We could derive those areas that might be suitable for developing more than one maritime activity. Such information, plus the information regarding to environmental status and ecologically significant areas, would inform about the risks.

[78] The MRECC method is designed for spatial planning, so the maximum spatial capacity of each maritime activities is determined by deducting the ecological protection areas with high importance and areas not suitable for specific activities. However, we need to modulate this, since this means that all the ocean (excepting unsuitable and protected areas) is suitable for any human activity, irrespective of the environmental impact.

[79] This is a qualitative analysis, synthesizing the assessment, current maritime activities and other analysis, to put forward the integrated layout for spatial utilization, and to provide suggestions to spatial planning.

7.3 Annex 3: Individual maps for Habitats

7.3.1 Seagrass

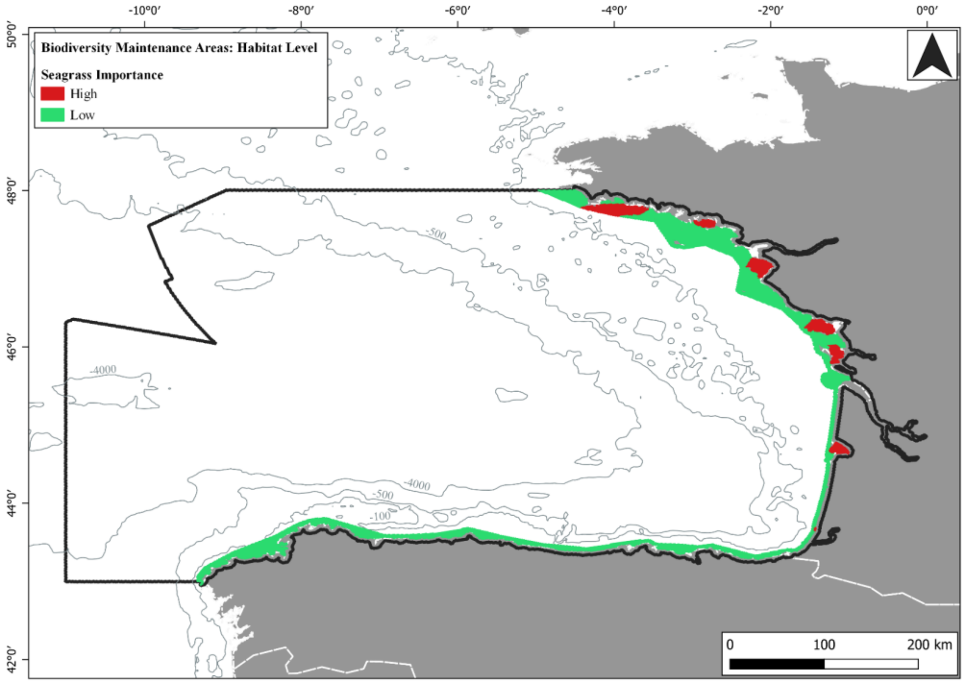

Figure 35. Seagrass habitat in the Bay of Biscay.

7.3.2 Seaweed habitats

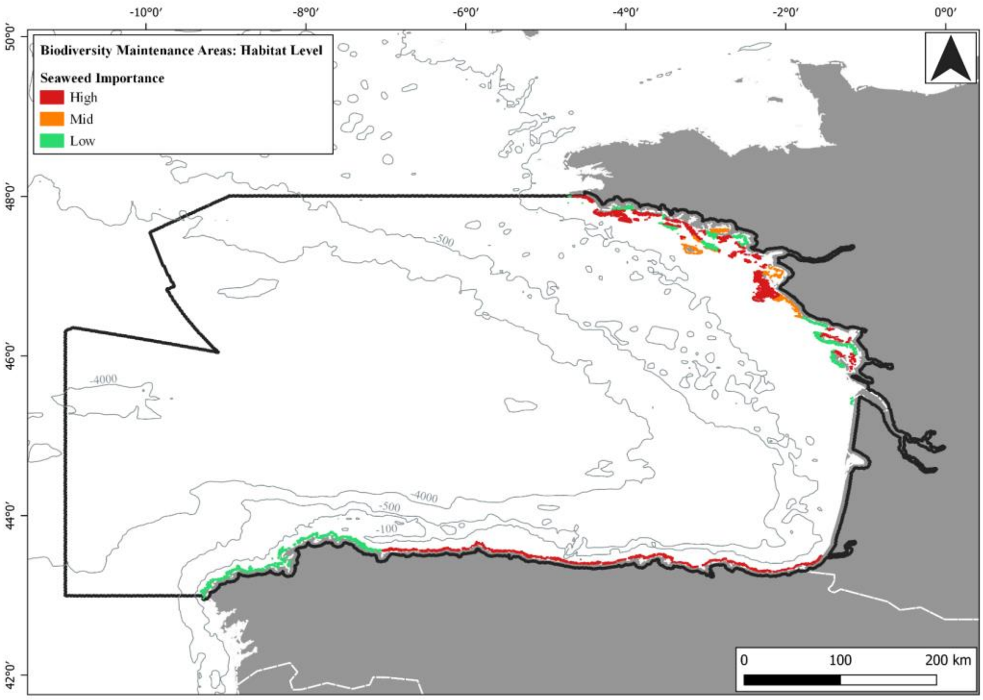

Figure 36. Seaweed habitats in the Bay of Biscay.

7.3.3 Coastal marsh

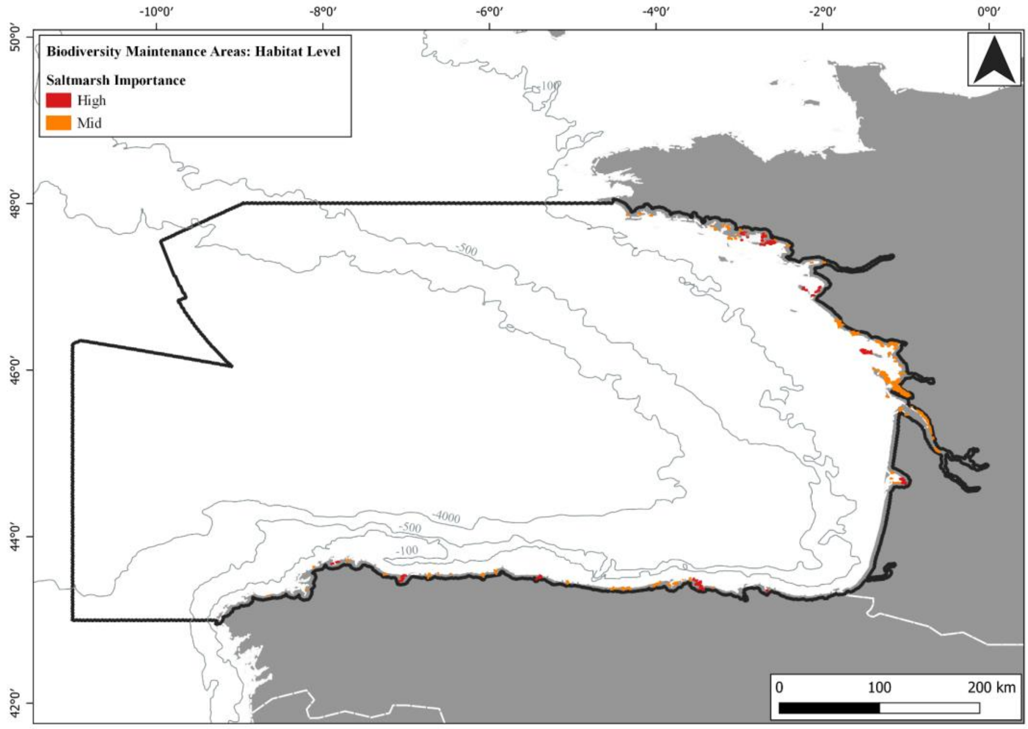

Figure 37. Coastal marsh habitat in the Bay of Biscay.

7.3.4 Tidal flats and shallow waters

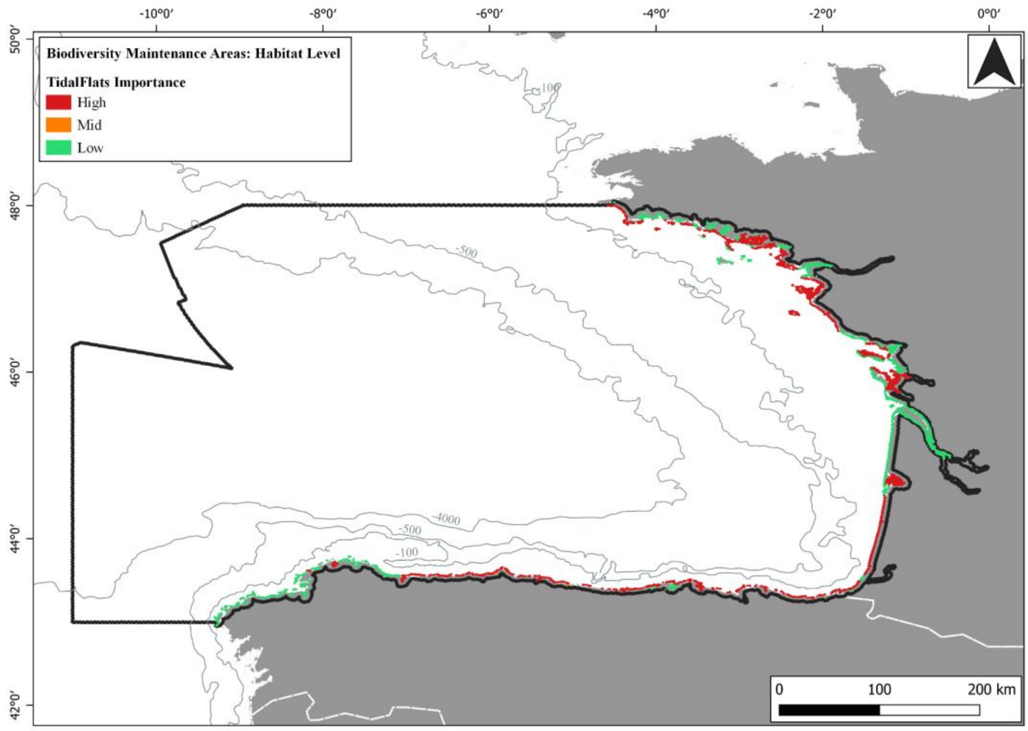

Figure 38. Tidal flats and shallow waters in the Bay of Biscay.

7.3.5 Estuaries

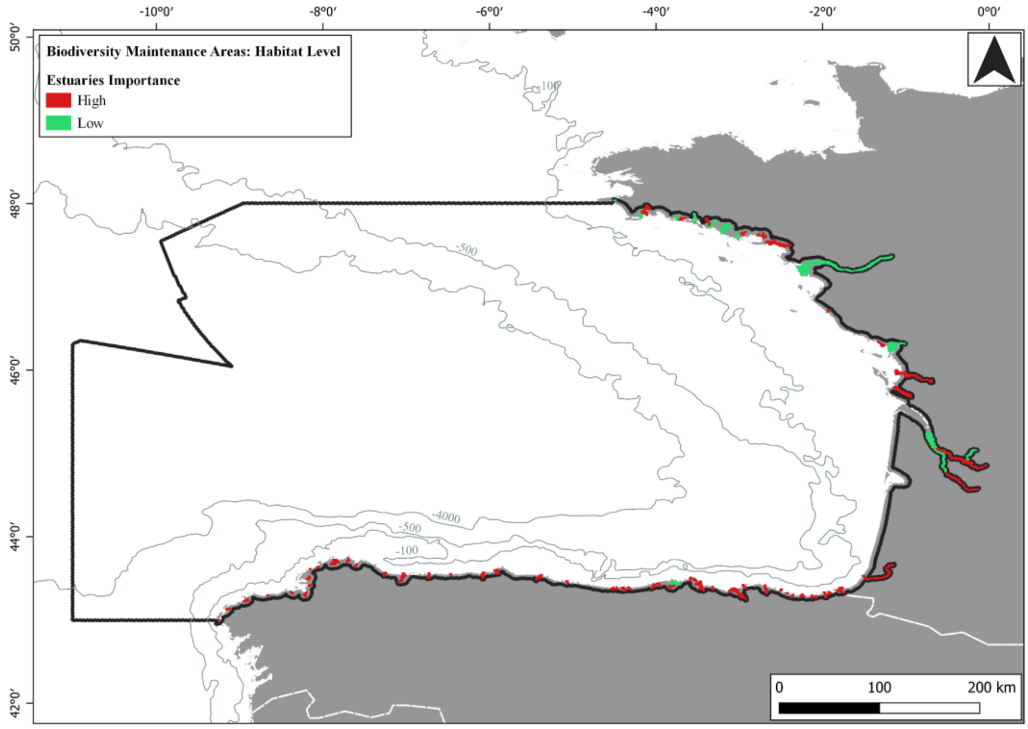

Figure 39. Estuaries in the Bay of Biscay.

7.3.6 Fishery growing areas

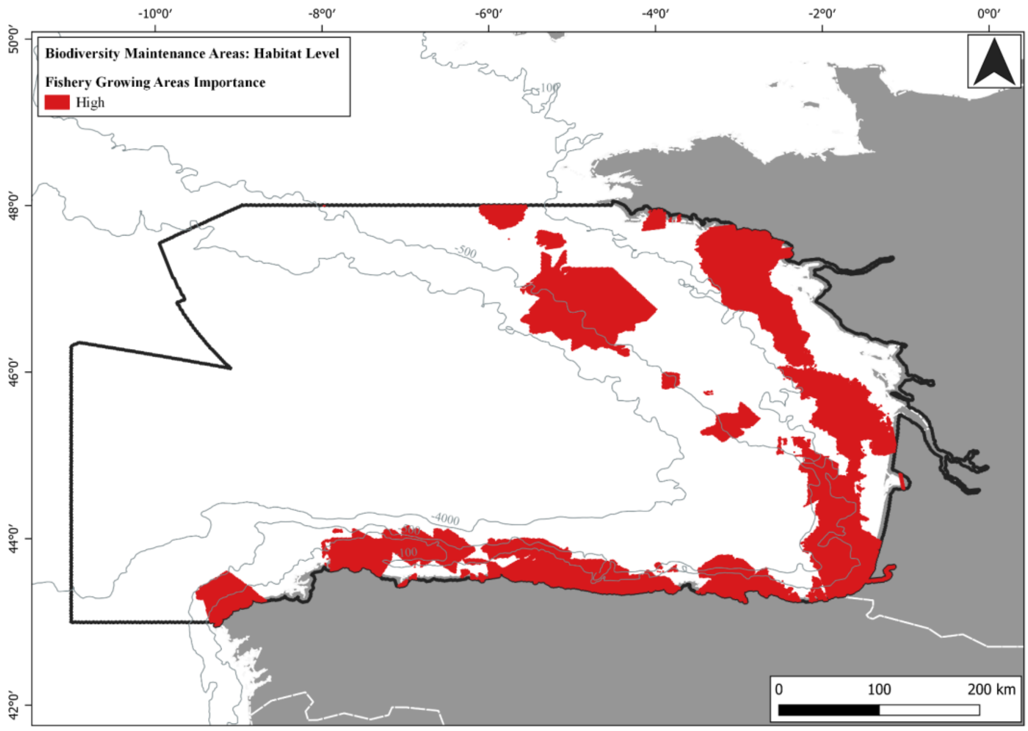

Figure 40. Fishery growing areas in the Bay of Biscay.

7.3.7 Other unique habitats

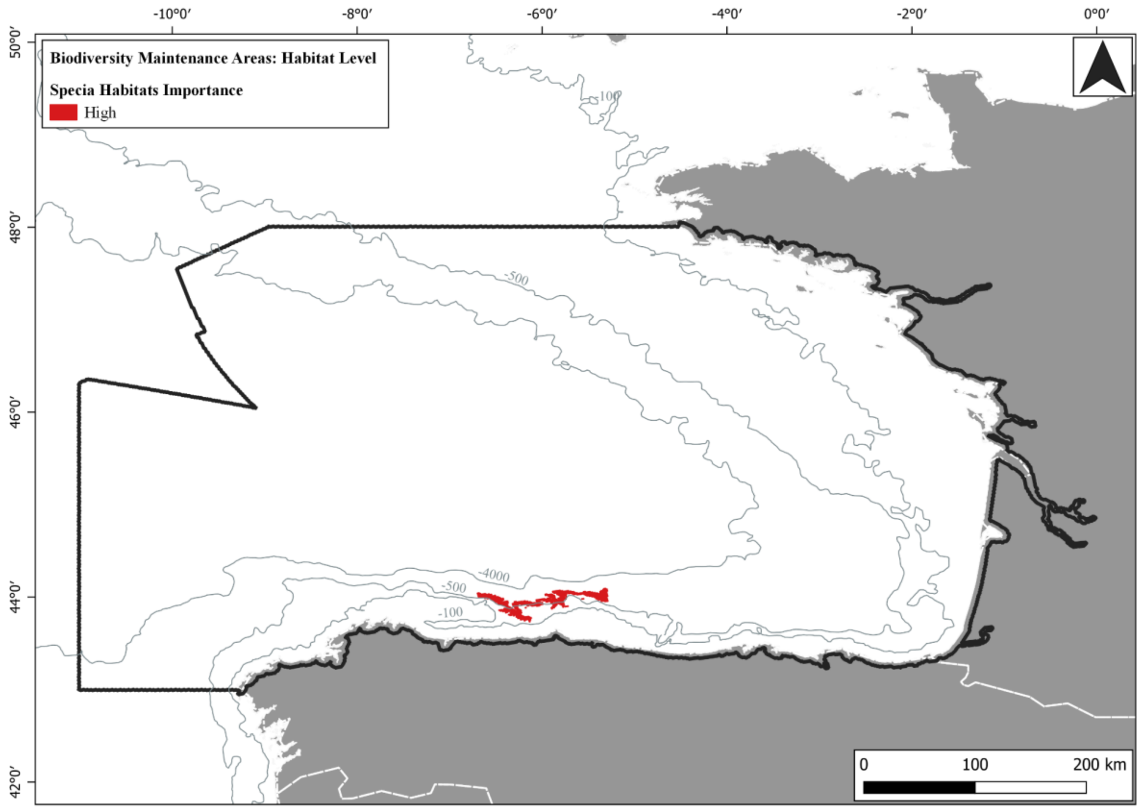

Figure 41. Other unique habitats in the Bay of Biscay.

7.4 Annex 4: Guidelines on the evaluation of the importance for Marine Ecological Protection

7.4.1 Disclaimer

This guideline is one of the outputs of China-EU Marine Data Network Partnership (CEMDnet) and its sister project the EMODnet Partnership for China and Europe (EMOD-PACE). They are projects for marine data cooperation between China and European Union under the framework of Blue Partnership for the Oceans. They are aimed at promoting ocean governance and science-policy interface between EU and China and support the implementation of UN Decade of Ocean Science for Sustainable Development and global commitments, by providing better data and data products.

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7.4.3 Foreword

The ocean is an important life-support system of our planet. Yet human activities at sea are rapidly increasing, resulting in cumulative pressures and effects on marine ecosystems. To minimize or removing these effects, various management responses have been implemented at global, supranational, or national scales. In this context, many countries around the world have implemented Maritime Spatial Planning (MSP), based on specific legislation, trying to find an equilibrium between growth and sustainability of human activities. For example, in the European Union (EU), the Maritime Spatial Planning Directive (MSPD) drives the future development of activities at sea, while at the same time good environmental status must be achieved in all regional seas, under the Marine Strategy Framework Directive (MSFD). In China, the Territory Spatial Planning has been redesigned, and "multi-plan integration" has been carried out, integrating various types of spatial planning into one unified framework. In the case of MSP, the Marine Functional Zoning and Marine Ecological Red Line are integrated as well, optimizing the layout of marine development and ecological protection. Besides, the evaluation of marine resource-environment carrying capacity (MRECC) and spatial development suitability (abbreviated as "double evaluation") is proposed along with these approaches, providing a scientific basis for spatial planning. By considering natural resources, environment and ecology, double evaluation provides an insight into ecological conservation and economic development trade-off, including the evaluation of the importance for Marine Ecological Protection (MEP), the suitability and maximum carrying capacity estimation for each economic activity.

In recent years, the cooperation between Europe and China on ocean issues has increased considerably. In this context, the CEMDnet and EMOD-PACE projects started, aiming at promoting ocean governance and science-policy interface between EU and China. One of the objectives is to compare European and Chinese modelling approaches for ecosystem vulnerability assessment. Hence, China's double evaluation approach was applied in a European subregion (the Bay of Biscay) to test the applicability.

One of the main components of double evaluation is the identification of important areas for MEP. Many countries and international organizations have carried out projects on identifying and setting up protected areas, including Alliance for Zero Extinction (AZE) sites, Important Bird and Biodiversity Areas (IBAs), Key Biodiversity Areas (KBA), Ramsar sites, as well as Ecologically and Biologically Significant Areas (EBSAs). China has always attached great importance to ecological protection. It was the first in the world to propose and implement the red line strategy. By conducting the evaluation of the importance for MEP, China has included areas with high importance for MEP into the red line system, contributing to the conservation of key natural ecosystems, biological resources, and habitats for key species. In the CEMDnet and EMOD-PACE projects, the method was also applied in the Bay of Biscay, and adjusted adaptively under the discussion of China and EU partners. Hence, these guidelines are prepared based on the evaluation method of the importance for MEP in China, combined with common application experiences in both China and Europe.

7.4.4 Guidelines on the evaluation of the importance for Marine Ecological Protection

1. Scope

These guidelines aim to describe purpose, process, and evaluation methods of the importance for Marine Ecological Protection (MEP). They can be used by regional or national organizations to identify important areas and importance level for MEP. The result can support the Maritime Spatial Planning (MSP), when evaluating an area for human activities and including the protection of areas of ecological importance, as well as for conservation, development and restoration planning.

It should be emphasized, however, that these guidelines are designed specifically to identify main ecological protection targets in China and Europe, providing a basic framework and technical method. In practice, it can be supplemented with other important characteristics, such as the ecosystem services provided or the vulnerable habitats and species present, and additional indicators can be selected or added to suit for local circumstances and ecological protection targets.

2. Purpose

This document provides guidelines for the application of a methodology to spatially assess the importance of protecting marine ecosystems, with the aim to identify important areas providing ecosystem services[80] or ecological vulnerable habitats and species, to determine the protection priorities, and to support ecological protection-related decision-making.

3. Process

3.1 Data collection

It is important to gather accurate, complete, relevant, and timely data. Essential data include: (i) monitoring or survey data of key habitat elements (e.g. submarine topography, seafloor types, oceanographical features), marine biodiversity and ecosystems; (ii) list of species and habitats of interest, such as protected, endangered or threatened species or habitats; (iii) spatially-explicit data of ecological zoning or management (e.g. Marine Protected Areas) or important wetlands; and (iv) other information related to regional ecological status, pressures and impacts.

[80] These guidelines evaluate areas which directly provide ecosystem services, or areas that could be relevant for the (theoretical) capacity of the system to provide ecosystem services.

3.2 Ecological protection target identification

The aim is to identify MEP targets from the aspects of ecosystem services and ecological vulnerability, and then determine their respective spatial distribution areas. Among them, these guidelines are prepared for marine biodiversity maintenance function, coastal protection function and the ecological vulnerability of coastal erosion and sand loss.

3.3 Evaluation of the importance for MEP

First, it is necessary to select evaluation indicators for each ecological protection target and determine the importance level of each distribution area. The importance level consists of two categories, i.e. highly important, areas for strict protection, and important, areas for general protection. Then, the results should be integrated into three aspects of biodiversity maintenance, coastal protection and vulnerability to coastal erosion and sand loss, by appropriate weighing coefficients (depending on the importance or vulnerability). At last, all the three aspects are integrated by the same weight to obtain the final evaluation result.

4. Evaluation method of MEP

4.1 Marine biodiversity maintenance function

The importance for marine biodiversity maintenance function is evaluated at three levels: species, habitat, and genes. Ecological protection targets include (i) distribution areas of important species (e.g. threatened, key protected, keystone species); (ii) typical habitats with high biodiversity, high productivity or important for life-history stages of species; (iii) areas with unique or unusual geomorphological or oceanographic features; and (iv) distribution areas of important aquatic genetic resources. Specific evaluation indicators and classification criteria are listed in Table 1.

Table 1. Evaluation indicators and classification criteria of marine biodiversity maintenance service.

Level	Ecological protection target	Indicator	Areas of high importance	Areas of importance
Species	Species distribution area	Species importance (threatened, key protected, keystone species)	Regional or national key protected species, critically endangered or endangered species, megafauna as regional keystone species	Local key protected species, vulnerable species, other keystone species
Habitat	Coral reef	Habitat area and coverage	All	
	Mangrove	Habitat area and coverage	All	
	Seagrass bed	Habitat area and coverage	All	
	Seaweed habitat	Habitat area	Cumulative area exceeding 50%	Others
		Primary productivity or chlorophyll	High	Medium and low
		Biodiversity (fish, mammals, etc.)	High	Medium and low
	Coastal marsh	Habitat area	Cumulative area exceeding 50%	Others
		Importance for life-history stages of species	Important migration and habitat of birds	Others

Level	Ecological protection target	Indicator	Areas of high importance	Areas of importance
		Vegetation coverage	High	Medium and low
	Tidal flats and shallow waters[81]	Habitat area	Cumulative area exceeding 50%	Others
		Diversity of benthos	High	Medium and low
		Importance for life-history stages of species	Important migration and habitat of birds	Others
	Estuary	Primary productivity or Chlorophyll	High	Medium and low
		Diversity (swimming species)	High	Medium and low
		Importance for life-history stages of species	Important migration and inhabitation for birds, spawning and migration for fish	Others
	Sea island	Importance for life-history stages of species	Important migration and habitat of birds	Others
		Diversity (mainly for species only occurring on the island and fishery resources in adjacent area)	High	Medium and low
		Vegetation coverage	High	Medium and low
	Fish nursery area	Importance of life-history stages of species (fish resources)	Spawning and nursery grounds	Important feeding ground, wintering field, migratory channels, etc.
		Population importance	Key species	Common species
	Other unique habitats	Unique	High in regional or national scale	High in local scale
		Diversity	High	Medium and low
Genes	Aquatic genetic resources	Importance for genetic resource protection	Core distribution region	Surrounding buffer region

4.2 Coastal protection function and the ecological vulnerability of coastal erosion and sand loss

The importance for coastal protection is evaluated by identifying habitats with coastal protection functions, such as vegetation community dominated habitats (i.e. mangroves, salt marshes), or habitats with high physical friction (i.e. bedrock coast, sandy coast). The ecological vulnerability to

[81] which are generally no deeper than 6 m, based on the definition in Ramsar Convention. But waters deeper than 6 m can also be included if it is of great importance for seabird habitat.

coastal erosion and sand loss is evaluated by identifying vulnerable natural coasts or those with natural attributes after ecological restoration.

Evaluation indicators include geological and ecological characteristics, such as slope, geomorphology, submarine habitats, emerged habitats, erosion rate, wave height, storm surge, etc. Models can be constructed based on main regional influencing factors, and weights can be made by experts' judgement.

The evaluation indicators and classification criteria of coastal protection function, from the Chinese method, are listed in Table 2.

Table 2. Evaluation indicators and classification criteria of coastal protection service.

Ecological protection target		Indicator	Areas of high importance	Areas of importance
Biological protection area	Salt marshes, mangroves, etc.	Habitat area, vegetation coverage, vegetation width	Large habitat area, high vegetation coverage, and large width[82]	Others
Physical protection area	Bedrock coast	Shore length	Longer coast exceeding 1 kilometre	Other
	Sandy shore	Shore length, width, slope	Large area, large width, and gentle slope	Other

The coastal erosion vulnerability is calculated[83] as:

$$V=(M+N)/2 \qquad \text{(Eq. 1)}$$

in which V is coastal erosion vulnerability, M is the dynamic factor of coastal erosion, which is calculated by erosion rate, N is natural factors of coastal erosion, being:

$$N= (g\times a_1 + h\times a_2 + Hw\times a_3)/3 \qquad \text{(Eq. 2)}$$

in which g is coastal sediment type, h is maximum water increment caused by storm surge, Hw is multi-year average wave height, and a is weighting factor based on expert judgements.

It is necessary to assign different scores to each indicator according to Table 3, and calculate the vulnerability score. Final vulnerability is categorized into 3 levels based on the scores, i.e. very vulnerable, vulnerable and less vulnerable.

Besides, sand loss vulnerable areas are determined based on very vulnerable sandy coasts.

[82] Indicators can be integrated by appropriate weights based on expert judgements. (see Borja et al., 2022)
[83] All data are into raster layers with the same resolution (e.g. 20 m) and do calculations between different layers.

Table 3. Evaluation indicators and classification criteria of coastal erosion vulnerability

Indicators		Scores		
		5	3	1
Coastal sediment type		Sandy/silty/muddy coast	Other natural coast	Artificial coast/ bedrock coast
Water increment by storm surge (m)		≥3.0	1.5~3.0	<1.5
Average wave height (m)		≥1.0	0.4~1.0	<0.4
Erosion rate (m yr^{-1})	Silty/muddy coast	≥10	1-10	<1
	Sandy coast	≥2.0	0.5-2	<0.5

European method is described in Borja et al. (2022a, 2022b), with adaptation to better reflect European environmental specificities and considering European Directives.

7.4.5 References

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7.5 Annex 5: Joint activities

7.5.1 Literature review

- NMDIS provided the initial official method and some associated literature;
- EU partners searched for additional literature;
- NMDIS and EU partners jointly revised the literature collated.

7.5.2 Method adaptation

- EU partners adapted the original method;
- NMDIS validated the changes;
- NMDIS and EU partners jointly determined the data to be used in the adapted method.

7.5.3 Method application

- EU partners collated the information to apply the methodology;
- EU partners applied the methodology;
- NMDIS validated the application;

7.5.4 Joint deliverables

Results from the joint activities in WP4, Task 4.2, were jointly analyzed and summarized into following deliverables:

- Deliverable 4.1 - Summary report summarizing choice of test areas, identification of data requirements and list of required data and data already gathered (M12)
- Deliverable 4.3 - Draft report on the suitability of ECC approach to Europe, showing the Bay of Biscay as an example (M24)
- Deliverable 4.5 – Final report on the "Marine Resource-Environment Carrying Capacity and Spatial Development Suitability" approach application to Europe, showing the Bay of Biscay as an example (M28)

7.5.5 Joint dissemination actions

Results from the joint activities in WP4, Task 4.2, were jointly disseminated in next actions:

- Open Access publication: Borja, A., S. Pouso, I. Galparsoro, E. Manca, M. Vasquez, W. Lu, L. Yang, A. Uriarte, 2022. Applying the China's marine resource-environment carrying capacity and spatial development suitability approach to the Bay of Biscay (North-East Atlantic). Frontiers in Marine Science, 9: 10.3389/fmars.2022.972448. Freely available at: https://www.frontiersin.org/articles/10.3389/fmars.2022.972448
- Oral presentation at 59th ECSA (Estuarine and Coastal Sciences Association) conference, held in San Sebastian, 5th – 8th September 2022: Borja, A., S. Pouso, I. Galparsoro, L. Castle, E. Manca, M. Vasquez, M. Lindh, L. Yang, A. Uriarte, Testing China's Environmental Carrying Capacity approach in the transboundary context of the Bay of Biscay (North-East Atlantic).