Universidad de La Laguna

CSIC Consejo Superior de Investigaciones Científicas

Facultad de Ciencias Universidad de La Laguna

Instituto Español de Oceanografía 1914

Spatial distribution of human pressures and the interaction with Benthic Broad Habitats; The case study of Central Cantabrian Sea

- Distribución espacial de presiones antrópicas y su interacción con los hábitats bentónicos. El caso de estudio del Cantábrico Central -

Máster de Biología Marina: Biodiversidad y Conservación

Ángela María Márquez Reyes

September 2022

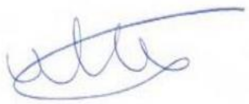
Universidad de La Laguna	AUTORIZACIÓN DEL TUTOR/ES	

La Dra. Covadonga Rodríguez González, Profesora Titular de la Universidad de La Laguna y el Dra. Ulla Fernández de Arcaya Redondo del Centro Oceanográfico de Santander (IEO, CSIC), como Tutora Académica y Tutora Externa, respectivamente,

DECLARAN:

Que la memoria presentada por Dña. Ángela María Márquez Reyes titulada "Spatial distribution of human pressures and the interaction with Benthic Broad Habitats; The case study of Central Cantabrian Sea", ha sido realizada bajo su dirección y consideran que reúne todas las condiciones de calidad y rigor científico requeridas para optar a su presentación como Trabajo de Fin de Máster, en el Máster Oficial de Postgrado de Biología Marina: Biodiversidad y Conservación de la Universidad de La Laguna, curso académico 2021-2022.

Y para que así conste y surta los efectos oportunos, firman el presente informe favorable en Santander y San Cristóbal de La Laguna, respectivamente, a 06 de Septiembre de 2022.



RODRIGUEZ GONZALEZ COVADONGA - 13763888K

Firmado digitalmente por RODRIGUEZ GONZALEZ COVADONGA - 13763888K
Fecha: 2022.09.06 10:54:22 +01'00'

Fdo. **Dra. Ulla Fernández de Arcaya** Fdo. **Dra. Covadonga Rodríguez González**

AGRADECIMIENTOS

Quería aprovechar para agradecer a todas las personas que han estado implicadas con el proyecto, sin las cuales no habría sido posible.

En primer lugar, mi más sincero agradecimiento a Ulla Fernández y Antonio Punzón, investigadores del grupo de estrategias marinas del Instituto Español de Oceanografía (IEO), por haberme dado la oportunidad de realizar este trabajo con ellos, y haber estado ahí para resolver todas mis dudas y problemas técnicos. He de decir que no tengo palabras para reflejar lo mucho que he aprendido con ellos, ha sido toda una oportunidad poder obtener un poquito del conocimiento que tienen.

Agradecer también al IEO, al CEDEX y al CSIC por los datos aportados al presente trabajo, que fueron necesarios para poder llevar a cabo el proyecto de investigación. No hubiese podido obtener estos resultados sin su ayuda.

Quiero agradecer a todos los amigos y familiares que han estado apoyándome, teniendo siempre palabras de ánimos en los momentos difíciles. En especial a mi madre, que, aunque no entienda muy bien lo que hago, siempre muestra una confianza extrema en el resultado.

Finalmente, quiero darle las gracias a David, por estar ahí siempre, incluso en la distancia.

INDEX

RESUMEN - ABSTRACT

Como consecuencia del elevado solapamiento de actividades en el ecosistema marino, surgen una serie de marcos de actuación para la protección de este medio, entre los cuales destaca la Directiva Marco de Estrategias Marinas (DMEM). En el presente trabajo se busca caracterizar las presiones que tienen una afección sobre el Descriptor 6 (D6), integridad del fondo marino, así como establecer una primera aproximación sobre las áreas de acumulación de estas. Para ello se ha realizado una recopilación de las actividades humanas que ocurren en el Mar Cantábrico central, las presiones que pueden ejercer, su zona de influencia y los hábitats bentónicos con los que solapan. Los resultados muestran que el Mar Cantábrico se encuentra altamente afectado, el 10% presenta pérdida física (1617,18 km^2) y el 42% del área estudiada está perturbada (6556,13 km^2). De hecho, 14 de los 21 hábitats estudiados mostraron más del 50% de su superficie afectada por la presión humana. La pesca es la actividad con mayor relevancia que afecta a la integridad de los fondos marinos (7415,19 km^2), ocurriendo esta actividad mayoritariamente sobre los fondos sedimentarios. La acumulación de las presiones se da en mayor medida en los hábitats litorales, donde los hábitats rocosos presentan un alto porcentaje de afección, siendo la fuente de esta acumulación la interacción entre diferentes artes de pesca (palangre y enmalle) en zonas de la plataforma y el talud (entre los 113-644 m) y la interacción de diferentes actividades en la costa. El resultado, son amplias zonas con presencia de presiones acumuladas, destacando la gran afección sobre el Lugar de Interés Comunitario (LIC) del sistema de cañones de Avilés, donde se acumulan hasta 3-4 presiones mayormente proveniente de la pesca. El estudio de la serie espaciotemporal de la pesca muestra un aumento general del esfuerzo de las artes fijas (35/40%) y una disminución general de las artes móviles (36/53%). El elevado solapamiento encontrado, así como el creciente uso de los espacios marinos, hace necesario el análisis minucioso de estas presiones para una correcta gestión de los ecosistemas y espacios protegidos.

The high overlap of activities in the marine ecosystem has driven the development of several frameworks for the protection of the marine ecosystem, among them, the Marine Strategies Framework Directive (MSFD) stands out. The present work aims to characterize the pressures that affect Descriptor 6 (D6), seabed integrity, and to establish the first approximation of the pressure accumulation analysis. To do it, a detailed compilation of the spatial distribution of the human activities that occur in the Central Cantabrian Sea, the pressures they may exert, the area of influence, and the overlapped benthic habitats have been conducted. The results showed that Central Cantabrian Sea is highly affected, the 10% of the seabed is physically lost (1617.18 km^2) and 42% of the surveyed area was disturbed (6556.13 km^2), in fact, 14 of the 21 studied habitats showed more than the 50% of their area affected by human pressures. Fishing is the activity exerting the greatest pressure on seabed integrity (7415.19 km^2) mostly occurring along sedimentary habitats. The results also showed that the pressures accumulation occurred mostly along coastal habitats, where rocky habitats present a high percentage of affection, being the source of this accumulation the interaction between different fishing gears (longline and gillnet) in deeper continental shelf and slopes (between 113 -644 m depth) and the interaction of different activities on the coast. The Site of Community Importance (SCI) Avilés Canyon System area also showed a high accumulation of pressures where up to 3-4 pressures were found, mostly fishing activities. The time series of fishing analyzed showed a general increasing trend of static gears (35/40%) while a general decrease trend of mobile gears (36/53%) was found. The high overlap found between pressures, as well as the increasing use of marine areas, makes it necessary to conduct a more detailed analysis of these pressures for the correct management of ecosystems and protected areas.

Palabras clave: Estrategias Marinas, hábitats, integridad de los fondos marinos, presiones acumuladas. | **Keywords**: Cumulative pressures, habitats, Marine Strategies, seabed integrity.

1. INTRODUCTION

The oceans are a very important resources for human beings, providing large number of services, both material and immaterial. Water bodies are affected by large number of human activities, from recreation to large-scale commercial activities such as fishing, oil exploitation or aquaculture. These activities and the pressures associated with them can therefore cause damage to ecosystems and their associated services (Andersen et al., 2013; Ban & Alder, 2007; Foley et al., 2010; Holon et al., 2015).

The human activities and pressures affecting ecosystems can occur simultaneously in time and space, causing the accumulation of these human-generated impacts. These activities can modify the environment in many different ways, such as polluted, increasing the turbidity, changing the salinity and water properties, destroying ecosystems, or altering ecosystem dynamics, among many others (Andersen et al., 2013; Ban et al., 2010; Foley et al., 2010). As a result, seas are affected in terms of their stability, from the local to the continental scale. In order to mitigate the negative effects of human practices on marine ecosystem dynamics, ecosystem-based management is beginning to be implemented. To achieve this, it is necessary to better understand the complex interaction between human activities, pressures and ecosystems components (Piet et al., 2021). The aim is to maintain a balance between all these components without putting biodiversity and ecosystems at risk (Andersen et al., 2020; Ban et al., 2010; Borgwardt et al., 2019).

With this objective in mind, the European Union’s Marine Strategy Framework Directive (MSFD Directive 2008/56/EC) was created with the aim to achieve Good Environmental Status (GES) along European waters. This Directive establishes a framework for action for all the countries of the European Union, with a total of 11 qualitative descriptors of GES that must be analyzed (Figure 1) in order to achieve the objectives established, and that are defined in Annex I of the directive (European Commission (EC), 2008).

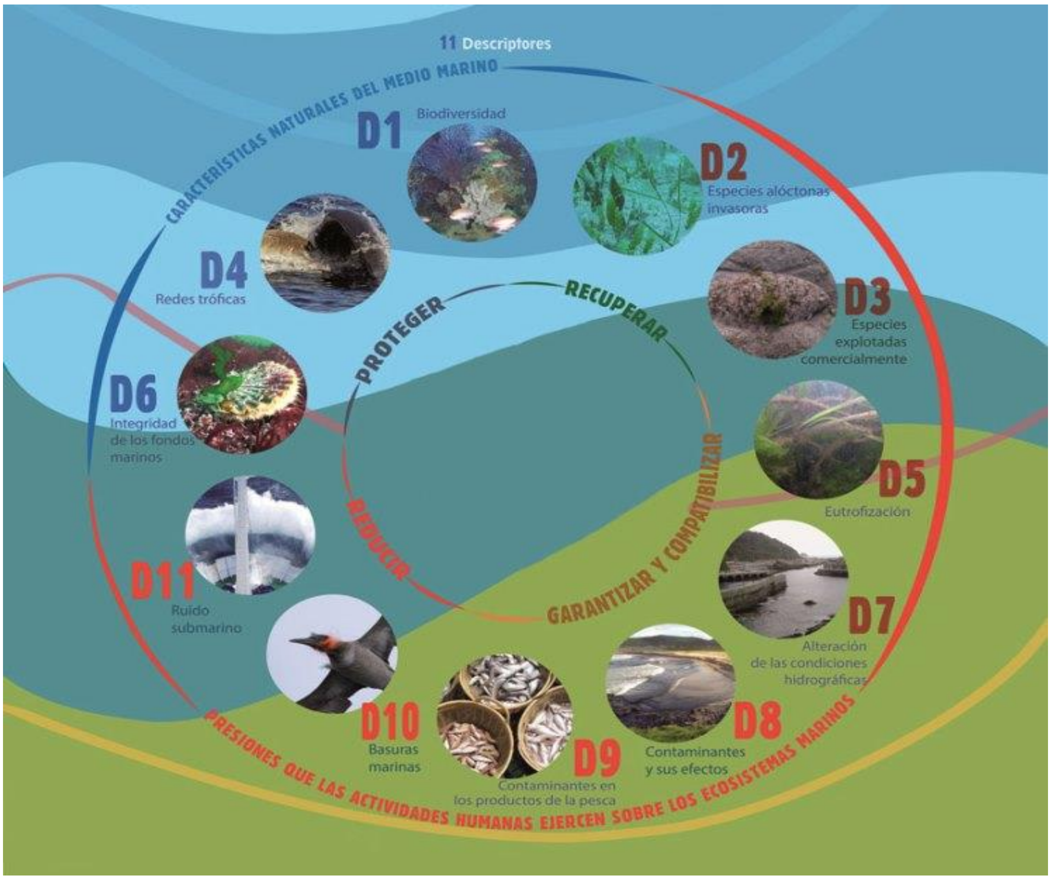


Figure 1. Descriptors defined in the MSFD, based on descriptor's type, either natural elements or human pressures. Resource: Ministerio para la Transición Ecológica y el Reto Demográfico (MITERD), 2022.

In the Marine Strategy Framework Directive, Descriptor 6 (D6) is defined as: "Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected" (EC, 2008). Rice et al. in their 2012 report, set out different criteria and indicators for determining GES for seabed integrity.

The steps to determine good environmental status are listed below (MITERD, 2012):

1. Identification of the most important or vulnerable habitats.
2. Identification of the pressures that may affect these.
3. Establish the status according to the percentage of habitat affected by the pressures or indicators derived from the most relevant habitats (richness or diversity).

Each descriptor is affected by different pressures, in the case of D6, the main pressures that are altering the integrity of the seabed are those ones generating seabed disturbance and seabed loss. Both lead to seabed disturbance, the difference between them being the ability of the seabed to recover after the pressure is applied to it. Thus, loss implies permanent changes to the seabed, whereas disturbance allows for a possible recovery of the altered biota over a 12-year period (International Council for the Exploration of the Sea (ICES), 2018; MITERD, 2019a; Raicevich et al., 2022). To assist in the management of this descriptor, the assessment of several criteria has been developed (EC, 2017b; ICES, 2019a):

- D6C1: Characterization of the location of physical loss (pressure).
- D6C2: Characterization of the location of physical disturbance (pressure).
- D6C3: Adverse effects of physical disturbance on habitats (impact).
- D6C4: Extent of habitats affected by physical loss (state).
- D6C5: Extent of adverse effects of anthropogenic pressures on the conditions of each habitat type (state).

In accordance with this descriptor, the MSFD, in the 2017 Directive (EC, 2017a, b), calls for the compilation of the activities that are causing different types of pressures (i.e. anchoring, aquaculture or fisheries) in the different countries, as well as establishing the level of affectation by accumulated pressures and determining the GES. In order to work on these aspects, Spain has created a spatial planning instrument for the marine environment, the Marine Strategies of Spain (EsMarEs), which establishes a framework for action at state level (MITERD, 2022). The first results were included in the report of the first implementation cycle (2012-2018) of the Marine Strategy Framework Directive in 2019.

One of the most pressing challenges of MSFD implementation is how to address the impacts of multiple activities, and their various associated pressures. For the assessment, a detailed characterization of the distribution of habitats and anthropogenic pressures, as well as the correlation between these and the ecosystem is needed. It is the basis of numerous other studies such as the development of ecological indicators or the design of marine reserves and conservation plans (Fernandes et al., 2018; Frazão-Santos et al., 2021; Holon et al., 2015; Judd et al., 2015; Kannen, 2014; Katsanevakis et al., 2011; Stelzenmüller et al., 2008). Some analyses of anthropogenic factors and their cumulative impacts on the ecosystem have been developed, globally and regionally (Andersen et al., 2013; Ban et al., 2010; Batista et al., 2014; Bevilacqua et al., 2018; Fernandes et al., 2017 & 2020; Halpern et al., 2008, 2009 & 2015; Knights et al., 2013; Korpinen et al., 2013; Selkoe et al., 2009). These consist of the characterization of activities and their associated impacts, using different criteria for their evaluation, such as duration, spatial extent, intensity, etc., with a semi-quantitative approach. (Andersen et al., 2013; Halpern et al., 2009; Holon et al., 2015; Willsteed et al., 2017).

The pressure accumulation analysis is even more necessary in areas included in the Natura 2000 network that are likely to be subject to significant impacts, as is the case of the Site of Community Importance (SCI) ESZZ12003 of the Avilés Canyon System, as well as other Special Areas of Conservation (SAC) or Special Protection Areas for Birds (SPA) that may be included in this network. The Natura 2000 network is a European ecological network of sites (both terrestrial and marine) for the conservation of natural habitats and their associated biodiversity included in the Habitats and Birds Directive (Directive 92/43/CEE & Directive 2009/147/CE), with the aim of protecting Europe’s heritage, which together with the MSFD constitute the pillars for the Integrated Marine Policy (IMP) (Fernandes et al., 2020; Möckel, 2017).

To support the objectives of the MSFD, this work has created a collection of spatial data on the main human activities taking place in the Central Cantabrian Sea, as well as their interaction with the Broad Benthic Habitats Types’ (BHT) established by the European Commission for Descriptors 1 (Biodiversity) and 6 (Seabed Integrity) (EC, 2008; Evans et al., 2016). These analyses are intended to conduct a complete analysis of the main human pressures affecting the Cantabrian seafloor, as well as respond to Criteria 1, 2 and 4 associated with Descriptor 6, and to contribute to the development of the Descriptors 3 and 5 (see an example of data flow in Figure 2).

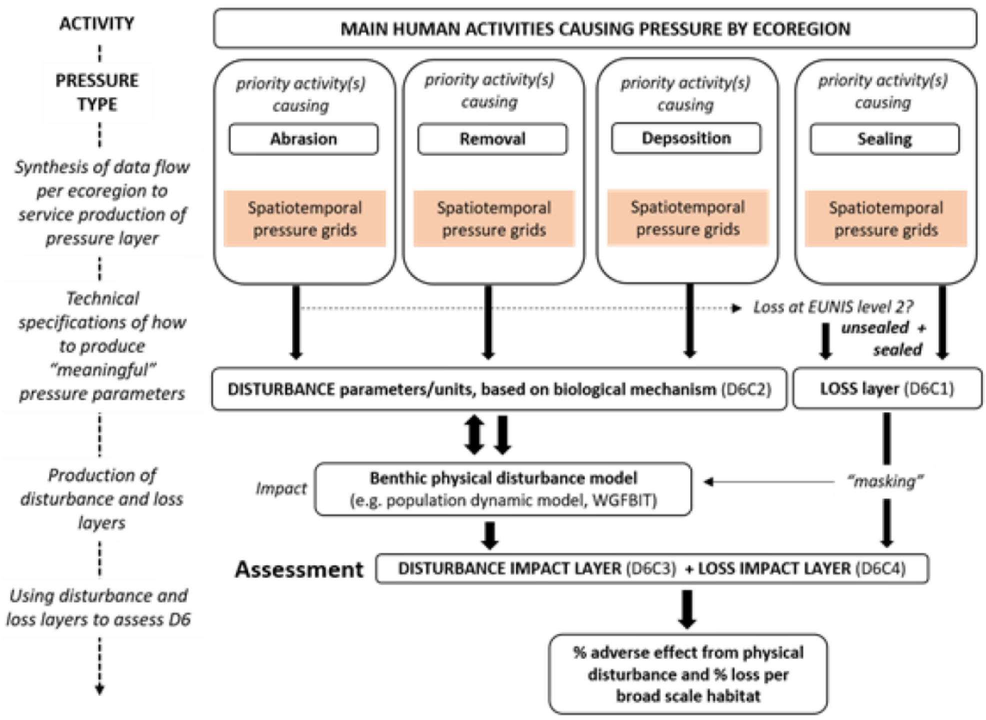


Figure 2. Example of dataflow for the collection of data for the Descriptor 6. Resource: ICES, 2019b

In addition, a methodological framework is created to analyze and mapping the cumulative human impacts pressures and the spatiotemporal analysis of the most relevant pressures, considering the requirements of the MSFD, in the Spanish territory.

2. OBJECTIVES

The main objective of this study is to identify and select the main pressures resulting from the human activities and characterize the cumulative pressure areas along Central Cantabrian Sea. Additionally, the pressures interaction with seafloor habitats is analyzed in the framework of MSFD in Spain. The specific objectives being:

- To identified, collect and describe the main anthropogenic activities and the pressure caused on the seafloor in the Central Cantabrian Sea.
- To analyze the spatial extent and distribution of the different human activities that cause physical disturbance or loss in the Central Cantabrian Sea.
- To calculate the broad benthic habitat types' (BHT) area affected by each human activity related to the MSFD D6C1, C2 and C4 assessment.
- Explore quantitative methodology for the analysis of cumulative pressures.
- Analyze the spatiotemporal trends of the main pressures along the study area.

3. MATERIAL AND METHODS

3.1. Study zone

According to the MSFD, Spain has 3 oceanic sub-regions: the Atlantic sub-region, the Mediterranean sub-region and the Macaronesian sub-region, including five official demarcations (Figure 3). This paper focuses on the Atlantic region, more specifically the study collected the human activities and pressures for the entire North Atlantic Demarcation, whereas for the analytical processes those ones causing seafloor disturbance and loss (seafloor contact) were selected.

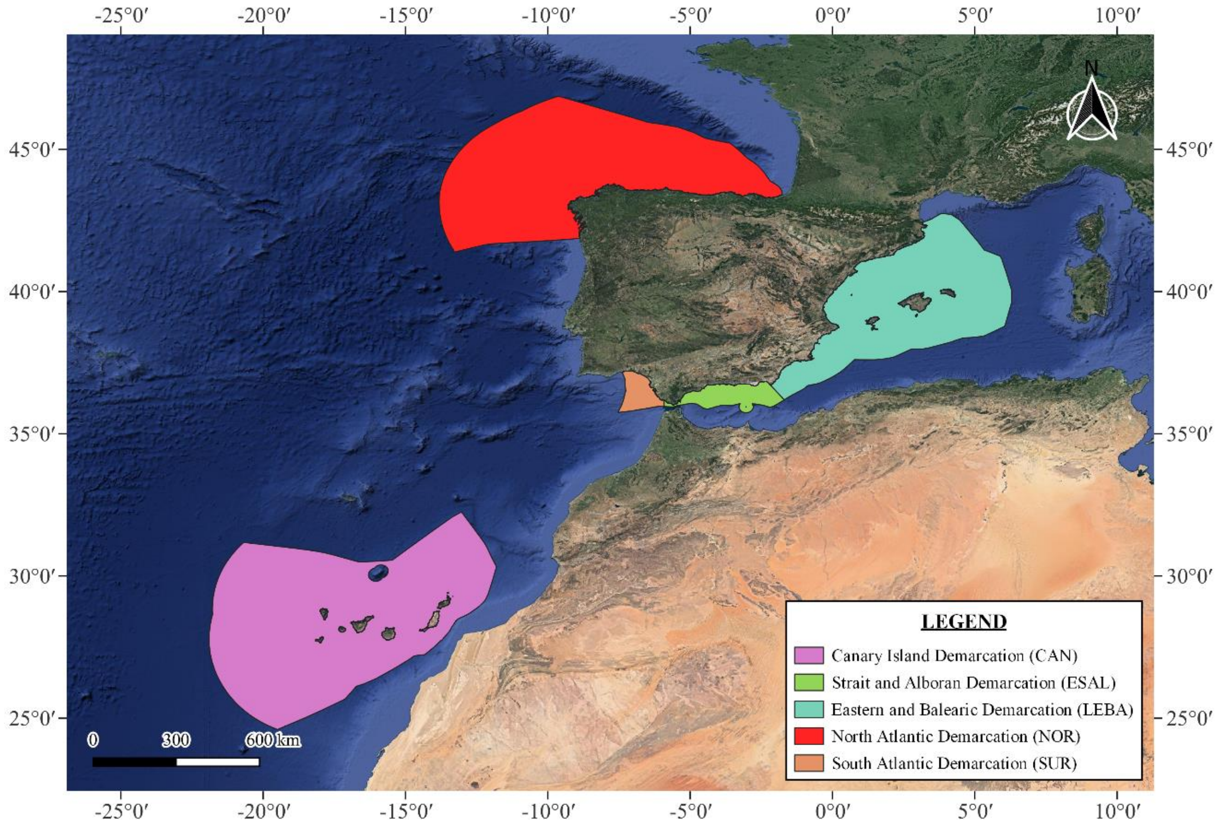


Figure 3. The five marine demarcations of the Spanish jurisdictional waters for implementation of the Marine Strategy Framework Directive. (MSFD DIRECTIVE 2008/56/EC). Resource: Elaborated by the author with data from MITERD.

For this project a central area of the Cantabrian Sea, located off the Asturian coast, has been selected. This area includes the Site of Community Importance (SCI) of the Avilés canyon system (SCI ESZZ12003), the Special Area of Conservation (SAC) of El Cachucho and the Special Protection Area for Birds (SPA) of Cabo de Peñas (Figure 4). These areas are of greater relevance, as their steep topography allows for a constant supply of nutrients and the settlement of habitat-forming species such as deep-sea corals and sponges, thus hosting a great diversity of species (García-Alegre et al., 2014; Ríos et al., 2022; Rodríguez-Basalo et al., 2021).

Figure 4 showed the study area and the location of the mentioned components, as well as the bathymetric lines drawing the topography of the seabed.

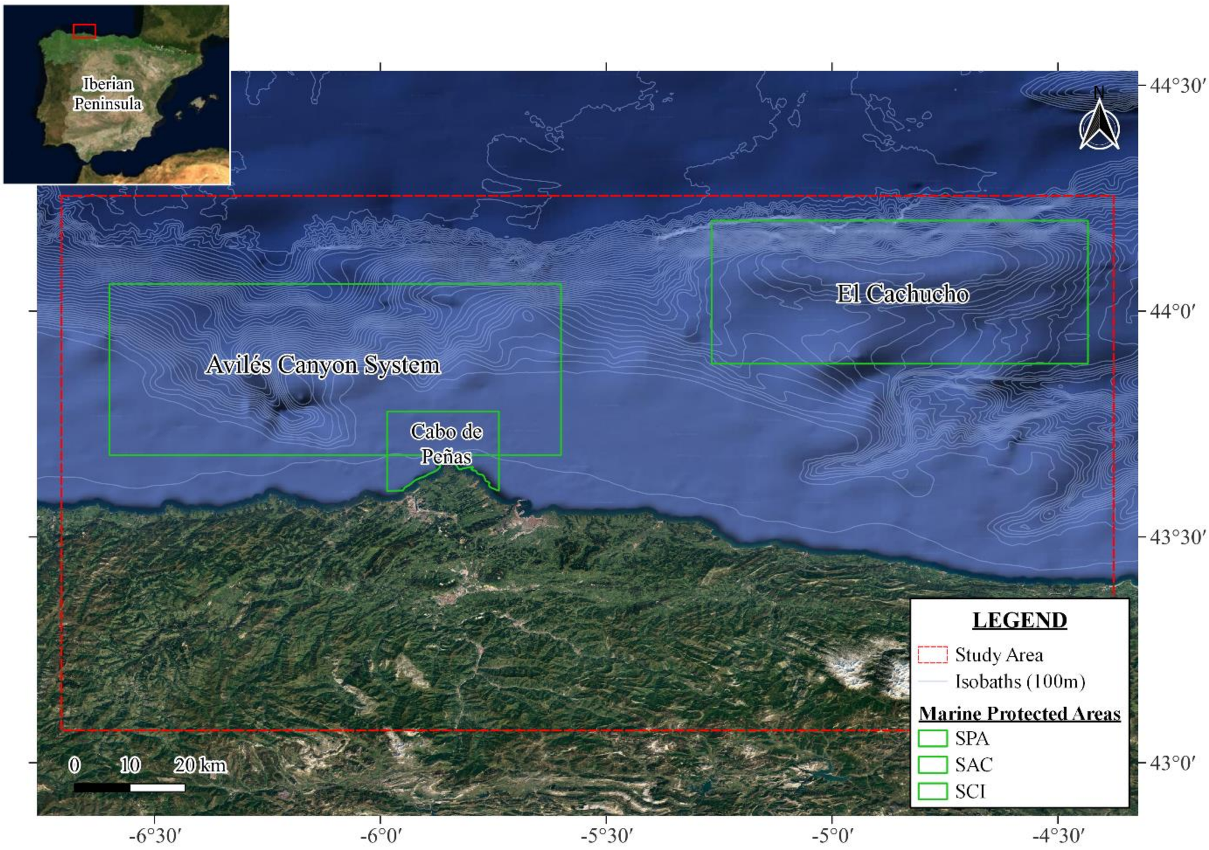


Figure 4. Map of the study area (Central Cantabrian Sea) including the SCI Avilés Canyon System and MPAs founds in the area; SAC El Cachucho and SPA Cabo de Peñas. The isobaths are represented every 100 meters.

3.2. Data collection

Information of the different activities in the study area has been collected from different sources based on the set of activities that are currently exerting pressure in the North Atlantic Demarcation according to the Marine Strategy Group (MITERD, 2019a).

The sources used in this study are some of those proposed by the International Council for the Exploitation of the Sea (ICES) in its reports focused on the different GES descriptors where they recommend the data flow process that must be followed to create pressure databases (ICES, 2018; ICES, 2019a). From all of them, the European Marine Observation and Data Network (EMODnet) platform is one of the most powerful data resources, which together with national sources such as the Centre for Studies an Experimentation in Public Works

(CEDEX), the National Institute of Statistics (INE) and the Spanish Institute of Oceanography (IEO) have been used to build the database used for the present study (Table 1). Furthermore, Table 1 showed the type of information that has been collected for each of the activities.

Table 1. List of the activities occurring in the study area, layer and data type and resource where they were obtained. ACe: Aquaculture Sites. ACf: Future Aquaculture. ACm: Molusc Aquaculture. MA: Military Areas. AR: Artificial Reef. C: Cables. DP: Population Density. D: Dredge Points. RE: Renewable Energies. Co: Collapse. OG: Oil & Gas. F: Anchoring Probability. P: Ports. DD: Dredge Disposal. VD: Vessel Density. OTB: Bottom Otter Trawls. LLS: Set Longlines. GNS: Set gillnets (anchored). PTB: Bottom Pair Trawls. CEDEX: Centre for Studies and Experimentation in Public Works. EMODnet: European Marine Observation and Data Network. INE: National Institute of Statistics. IEO: Spanish Institute of Oceanography.

Activity		Layer type	Data type	Resource
ACe		Polygon	Area of aquaculture sites (km^2)	CEDEX
ACf		Polygon	Area of possible use for aquaculture in the future (km^2)	CEDEX
ACm		Polygon	Area of mollusc production sites (km^2)	CEDEX
MA		Polygon	Area of military activities (km^2)	EMODnet
AR		Polygon	Area occupied by artificial reefs (km^2)	CEDEX
C		Polylines	Position of the cable route (km)	CEDEX EMODnet
DP		Polygon	Inhabitants per csquare kilometer (population/km^2)	CEDEX INE
D		Point	Location of dredge points (location by coordinates)	EMODnet
RE		Point	Area of possible renewable energies location (location by coordinates)	EMODnet
Co		Point	Location of collapses such as boats (location by coordinates)	CEDEX
OG		Point /Polygon	Location and area of oil and gas extraction (location by coordinates)	EMODnet
F		Polygon	Location of commercial anchoring probability calculated by AIS (km^2)	CEDEX
P		Points	Location of ports (location by coordinates)	EMODnet
DD		Points	Location of dredge disposal points (location by coordinates or km^2)	CEDEX EMODnet
VD		Raster	Hours per square kilometer per month (hour/km^2/month)	EMODnet
Fishery	**OTB***	Polygon	Average working hours 2019 (hour/km^2)	CEDEX IEO
	LLS*			
	GNS*			
	PTB*			

***Nomenclature based on Coordinating Working Party on Fishery Statistics (CWP), 2016.**

The information of the activities has been compiled in shapefile (.shp) format in most cases, and these files can be of different types: polygon, polyline or point. The maritime traffic density was obtained in raster format. After all layers were compiled, the representation of all the activities occurring on the study area was carried out.

Once the activities that take place in the selected area had been compiled, a bibliographic review by manual search in key journals and grey literature was carried out to find out the pressures exerted by each of the activities, as well as to determine whether the pressures generated by these activities had a zone of affection beyond the local impact, and thus be able to include it in the analysis. At this point it is necessary to comment the difference between activity and pressure:

- **Activity**: These are the human activities which are needed to meet the requirements of our society. An activity can cause different pressures with different scales of impact (ICES, 2019b).
- **Pressure**: It is described as the mechanism by which an activity has an effect on the ecosystem, actual or potential. One pressure can be caused by different activities (ICES, 2019b).

With all this information, it was possible to draw up an activity-pressure interaction matrix with the area of influence of each activity, having into account the pressures that can be caused.

Similarly, information of the benthic habitats present in the area was compiled according to the classification of habitat types made by the European Commission in 2017, for descriptors 1 and 6 (EC, 2017a; Evans et al., 2016). This information was collected from EMODnet, which produced the map based on the 2021 EUSeaMap, multi-resolution full coverage of all European seas including bathymetry, geology and habitats which is a predictive map with a resolution of approximately 250 meters (Vasquez et al., 2021). Figure 5 showed the habitat distribution in the study area, and the area and depth range distribution of each of the habitat used is listed in Table 2:

1. Infralittoral:
   - Infralittoral mud
   - Infralittoral sand
   - Infralittoral coarse sediment
   - Infralittoral rock and biogenic reef
2. Circalittoral:
   - Circalittoral mud
   - Circalittoral sand
   - Circalittoral mixed sediment
   - Circalittoral coarse sediment
   - Circalittoral rock and biogenic reef
3. Offshore circalittoral:
   - Offshore circalittoral mud
   - Offshore circalittoral sand
   - Offshore circalittoral mixed sediment
   - Offshore circalittoral coarse sediment

- Offshore circalittoral rock and biogenic reef

4. Upper bathyal:
   - Upper bathyal sediment
   - Upper bathyal sediment or Upper bathyal rock and biogenic reef
   - Upper rock and biogenic reef

5. Lower bathyal:
   - Lower bathyal sediment
   - Lower bathyal sediment or Lower bathyal rock and biogenic reef
   - Lower bathyal rock and biogenic reef

6. Abyssal

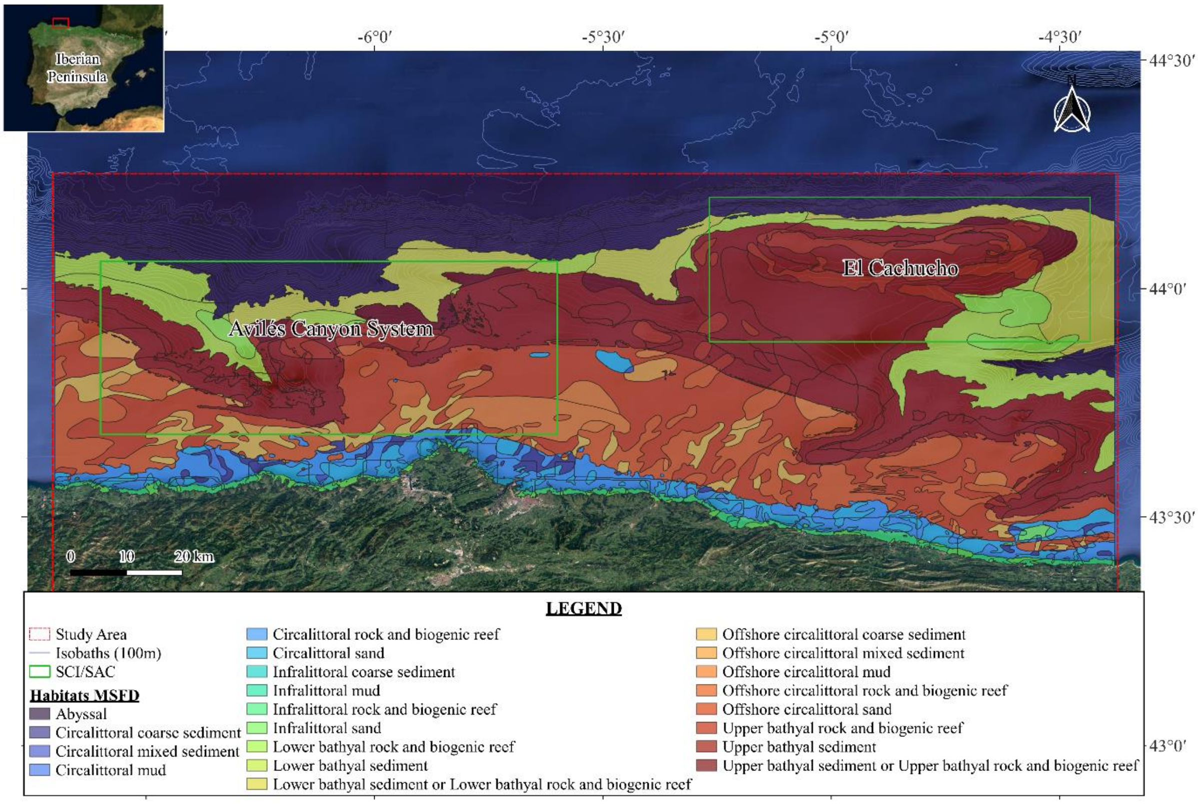


Figure 5. Habitats of the study area according to MSFD. The figure includes the SCI Avilés Canyon System and SAC El Cachucho. The isobaths are represented every 100 meters. Resource: Own elaboration with EMODnet (2021) data.

Table 2. List of the MSFD broad habitats in the study area showing for each habitat the number of csquare (Csq) and total area (km^2) covered, mean and standard error (se) depth, and depth range (min and max).

BHT	BHT	Csq	Area	Depth (m)			
	(acron)	(n)	(km^2)	mean	se	max	min
Abyssal	Abyss	3680	3264,82	4441.7	7.3	5365	2152
Circalittoral coarse sediment	CirCs	118	105,66	58.7	3.5	77	30
Circalittoral mixed sediment	CirMs	4	3,58	34.3	7.8	76	11
Circalittoral mud	CirMu	12	10,75	48.9	5.9	95	19
Circalittoral rock and biogenic reef	CirRo	674	603,82	49.3	1.7	95	6
Circalittoral sand	CirSa	458	410,34	48.1	2.2	97	3
Infralittoral coarse sediment	InfCs	1	0,90	7.0	NA	7	7

BHT	BHT	Csq	Area	Depth (m)			
	(acron)	(n)	(km^2)	mean	se	max	min
Infralittoral mud	InfMu	4	3,59	0.3	8.6	11	26
Infralittoral rock and biogenic reef	InfRo	183	164,10	3.3	4.7	29	64
Infralittoral sand	InfSa	92	82,49	15.7	1.5	23	3
Lower bathyal rock and biogenic reef	LBatRo	220	195,93	1663.5	50.2	2214	1219
Lower bathyal sediment	LBatSed	1079	960,79	1595.2	24.9	2370	988
Lower bathyal sediment or Lower bathyal rock and biogenic reef	LBatSed/Ro	1090	968,95	1822.0	9.2	2475	1192
Unidentified	Unidentified	2	1,79	132.5	24.6	177	68
Offshore circalittoral coarse sediment	OfCirCs	410	366,59	112.8	3.0	164	57
Offshore circalittoral mixed sediment	OfCirMs	151	134,74	146.8	5.3	200	81
Offshore circalittoral mud	OfCirMu	366	327,10	140.7	2.1	200	60
Offshore circalittoral rock and biogenic reef	OfCirRo	1262	1128,77	119.2	2.5	191	74
Offshore circalittoral sand	OfCirSa	2167	1936,76	141.7	1.7	202	62
Upper bathyal rock and biogenic reef	UBatRo	659	586,39	644.4	33.1	1246	164
Upper bathyal sediment	UBatSed	4099	3653,33	603.1	12.6	1292	156
Upper bathyal sediment or Upper bathyal rock and biogenic reef	UBatSed/Ro	260	231,24	1026.5	13.3	1336	465

On this study, for this first approximation, only the pressures having contact with the seafloor have been analyzed (D6C1 y C2), because these are the main impacting drivers and are directly related with the seafloor impact (ICES, 2019b).

3.3. Data analysis

Once the information of each selected activity and pressure was collected, they were processed and selected, leaving only the activities that were present in the study area. For the preparation of each spatial layer different tools were used including clipping of layers, merging between several layers, generating buffers or vectorization of raster layers, among others.

The whole process was carried out with the free geographic information software QGIS v3.22. The geographic data were loaded into this software, and with the layers already processed, map compositions were made.

For the data analysis and management, the R v.4.2.0 software was used, for which the raster, sf, sp, dplyr, classInt, rgdal, vmstools, tidyverse and lwgeom packages were used, as well as a modified script of the Csquare function of the VMSTOOLS package. Some of the most used scripts are included as supplementary materials.

For the spatial analysis, all the information was included in a grid built called Csquare, based on the methodology developed by the Marine and Atmospheric Research in Australia (CSIRO). It is a system for storage, querying, display and exchange of "spatial data" locations and extends in a simple way so that everyone can use it. It consists of the generation of a georeferenced grid, measured in degrees of latitude and longitude, in which each csquare has a unique code (Rees, 2003).

This spatial grid is used by MSDF to represent and share data globally, and a 5x5 km^2 grid is generally used for GES descriptor 6 because of data collection limitations (ICES, 2018; ICES, 2019a). However, in the present work, due to the small working area, a 1x1 km^2 grid has been chosen in order to include a more detailed result.

With the data already prepared and the grid created, all the activities were joined together in a dataframe. The following results were obtained from this dataframe, including the number of csquares affected and the area in km^2 affected. The following parameters were calculated:

- Total seafloor area (km^2) lost and perturbed.
- Total area affected (km^2) by total and each activity, respectively.
- Total area (km^2) affected by two different activities overlapped at the same time.
- Total area (km^2) affected by accumulated pressures (1, 2, 3-4 and ≥5 pressures).
- Total number of Csquares, total area (km^2) and the total percentage (number of csquares affected/total habitat number of csquares) affected by broad habitat type (BHT).
- Number of habitats affected by percentage of pressure affection.

In the habitat analysis, those csquares identified as Unidentified have not been taken into account.

In order to adopt precautionary measures, all the areas' calculations and spatial representations were conducted considering the area where the activity exert the pressure and the buffer area obtained from the literature. Human activities exert pressures that have effects that may lead to impacts on receptors, following Elliott et al. (2020) this effect may be additive, synergistic, antagonistic (compensatory), or masking, however, in this study we only consider addition, also when we calculated the activities generating habitat loss.

The spatial distribution maps resulting from the analysis were produced with the QGIS v3.22 geographic information system again.

Finally, an example of how the spatiotemporal variability of pressures accumulation could be analyzed is presented. For this purpose, the pressure of fishing was selected, because of the relevance of this human activity in the study area (both in terms of distribution and intensity) and because we had access to a large time series data (2009-2021). The temporal trend of fishing intensity (hour/km^2) for the four different fishing gears (Set Longlines (LLS), Bottom Otter Trawls (OTB), Set gillnets (GNS) and Bottom Pair Trawls (PTB)) was analyzed, for the period 2009-2021. To do that we conducted a nested Generalized Linear Model (GLM) (1) using a script in R v.4.2.0 software (2; see supplementary material for more information) obtaining the temporal trend of fishing intensity (hour/ km^2) by csquare.

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \varepsilon \quad (1)$$

glm (formula = hour ~ year + gear, data = dbhora2)   (2)

The year was nested to the study zone, obtaining a specific coefficient and a *p* value for every csquare, describing the positive or negative relationship (by means of the coefficient) between the intensity and time over the study zone. Csquares with three or less years of data were deleted for the analysis. The matrix resulting from the analysis will be provided as digital supplementary material. With these results, the correlation tendency (positive or negative) and significance were represented using QGIS v3.22.

4. RESULTS

4.1. Human activities distribution

In total 17 activities were identified and described for the entire North Atlantic Demarcation, from these, 15 were also located in the study area (the Central Cantabrian Sea). Figure 6, shows the spatial distribution of the activities in the whole North Atlantic Demarcation, where two groups of activities can be identified, those with a more specific location, such as port infrastructures or artificial reefs, and another with a wider distribution (density of maritime traffic, fishing or military areas).

The results showed that most of those activities occurred along the coastal area, while fishing is the most widespread pressure along the deeper continental shelf and slope areas. The results also showed that a large area of the SCI Avilés Canyon System was affected, where 5 activities are found inside the protected area (cables, prospections, vessel density, military area and fishery). In contrast the number of activities exerting pressures inside the SAC area of El Cachucho is lower (military area and fishery).

Each activity will give rise to many pressures, for this reason, in this study, for each of these activities, the pressures that they can generate have been identified, as well as the area of influence (Table 3). According to previous studies, all the activities are found to generate more than one pressure in space and time, but it is the extraction of dredged material and aquaculture those activities that generate higher number of pressures on the environment (Table 3).

The area of influence varies greatly depending on the type of activity and pressure. Biological pressures or those ones introducing substances into the system affect the greatest distances (up to 100 km) (i.e. aquaculture and maritime transport), while the potential impact of activities generating physical pressures are limited to a local impact or to a few kilometers (1-5 km) (i.e. Cables and collapses).

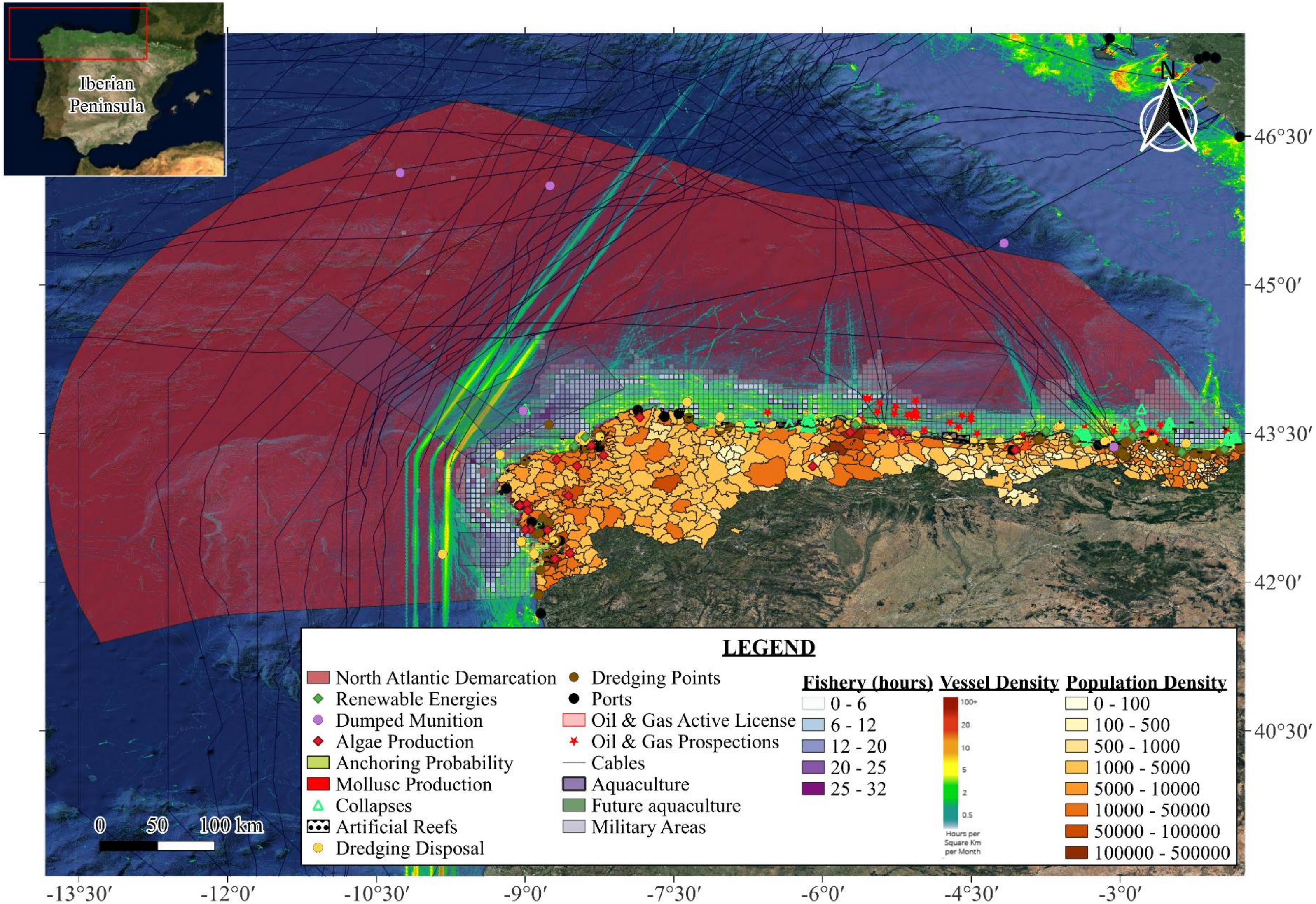


Figure 6. Compilation of activities exerting pressures in the North Atlantic Demarcation.

It is needed to comment, with regard to Table 3, that other resources such as Bevilacqua et al., (2018), Holon et al., (2015) or Andersen et al., (2020) give a generalized influence distance, associating only one value for all the pressures related to an activity.

From all the activities analyzed, 11 of them exert a direct physical pressure on the seabed causing either loss or disturbance. These human activities are shown in Figure 7, and described in Table 3. Most of the physical pressures exert local or 1 kilometer effect around their point of occurrence.

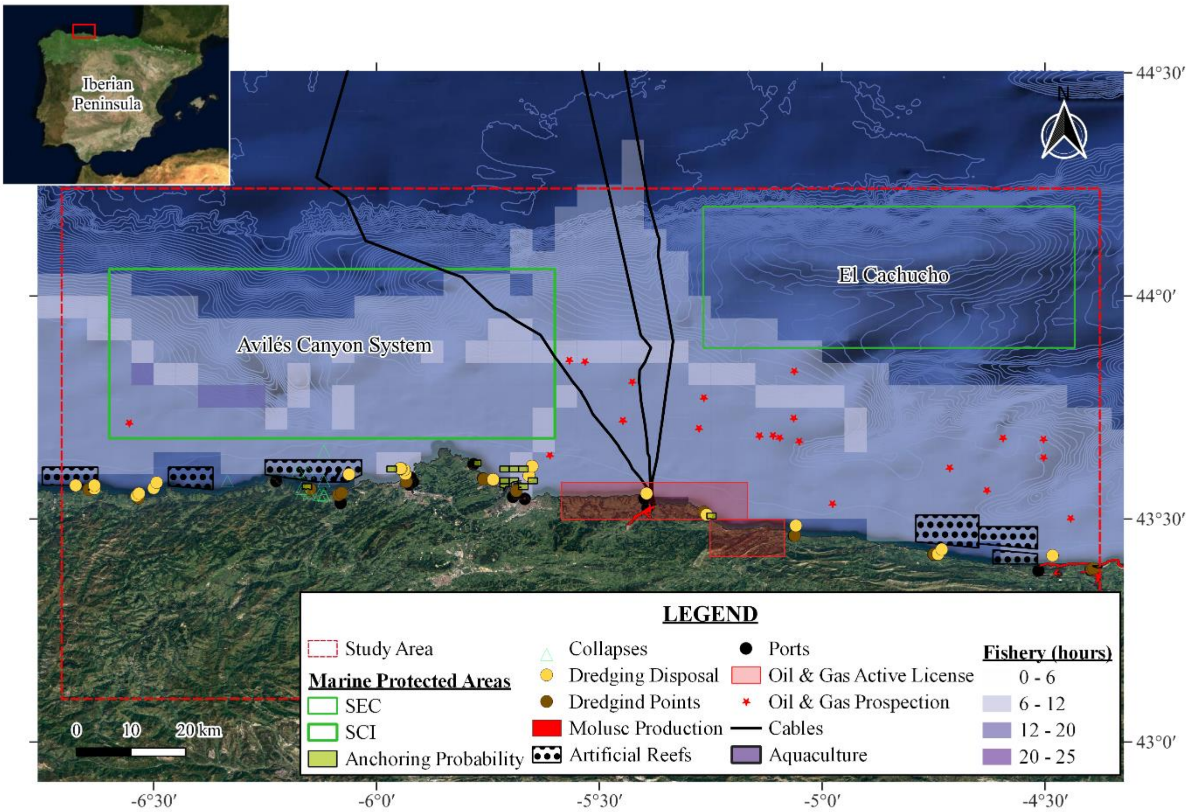


Figure 7. Human activities causing physical damage occurring in the study area.

Table 3. Interaction matrix of activity-pressure and their influence distance on the study area. Green: those activities-pressures which interact**.**

Pressures/Activities	**Infrastructures (ports, docks, etc.)**	**Prospections**	**Renewable Energies**	**Dredging (extraction points)**	**Dumping**	**Cables**	**Military Areas**	**Artificial Reef and other structures (dumped munition and collapse)**	**Aquaculture establishment**	**Shellfish Aquaculture**	**Future Aquaculture**	**Maritime Transport**	**Anchoring**	**Population Density (infrastructures)**	**Fisheries (Bottom & Pelagic)**	**Resource**
Physics																
Habitat disturbance		Local	Local	1 km	1 km	Local	1 km	1 km	5 km	Local	5 km	1 km	Local	Local	Local	a, c, d, e, f, g, h, i
Habitat loss	Local	Local	Local	1 km	1 km	Local		*Local*	Local	Local	Local		Local			a, c, d, e, g, h
Increase of turbidity	1 km	1 km	Local	1 km	1 km	Local			5 km		5 km	1 km	Local	Local	Local	d, e, f, g, h
Changes to hydrological conditions	1 km	1 km	1 km	1 km	1 km	1 km		1 km						Local		b, c, d, e, f, g
Organic and inorganic substances																
Nutrient/Organic enrichment				1 km	1 km				1 km	5 km	1 km			24 km	1 km	b, c, d, e, f, g, i
Contamination	5 km	5 km			10 km	1 km	Local	1 km	3 km	1 km	3 km	20 km		5 km		c, d, e, f, g, h, i
Input of litter						20 km		20 km	20 km	20 km	20 km	100 km	1 km	Local	Local	b, c, d, e, f, g, i
Energy																

Pressures/Activities	**Infrastructures (ports, docks, etc.)**	**Prospections**	**Renewbable Energies**	**Dredging (extraction points)**	**Dumping**	**Cables**	**Military Areas**	**Artificial Reef and other structures (dumped munition and collapse)**	**Aquaculture establishment**	**Shellfish Aquaculture**	**Future Aquaculture**	**Maritime Transport**	**Anchoring**	**Population Density (infrastructures)**	**Fisheries (Bottom & Pelagic)**	**Resource**
Antropogenic sound	5 km	20 km	20 km		20 km	20 km	10 km	20 km	20 km	20 km	20 km	14 km			1 km	b, c, d, e, f, g, h, i
Other energetic forms			Local			Local		Local								c, d, e, g, h
Biological																
Patogens						50 km			75 km	20 km	75 km					b, c, d, e, f, g, i
Input or spread of non-indigenous species	5 km	50 km							50 km	100 km	50 km	50 km				b, c, d, e, f, g
Species perturbation		10 km	10 km			10 km			10 km	10 km	10 km				Local	c, d, e, f, g, h, i
Community perturbation									50 km	50 km	50 km					c, d, e, f, g, i
Resource	3, 4	2, 3	1, 2, 3, 6	3, 4	1, 2, 3	1, 2, 3	3	2, 3	1, 2, 3, 4	1, 2, 3, 4	1, 2, 3, 4	3, 4	3	3, 4, 5	3	

Interacction activity-pressure:
a) ICES, 2019a
b) EC, 2008
c) MITERD, 2019a
d) Oosterbaan et al., 2009
e) Anderson et al., 2013
f) Ban et al., 2010
g) Fernandes et al., 2020
h) Hammar et al., 2020
i) Babosa et al., 2018

Influence distance:
1. Hammar et al., 2020
2. Fernandes et al., 2020
3. Anderson et al., 2013
4. Ban et al., 2010
5. Batista et al., 2014
6. Fernandes et al., 2021

Italic letters: Personal approach

4.2. Distribution of activities causing seafloor loss and/or disturbance and their overlap with habitats (BHT)

From 15735,3 km^2 extension of the study area, a total of 6557 km^2 are affected by the 11 different human activities. Of this area, a total of 1617 km^2 were loss pressured (10% of total area), while over 6556 km^2 were disturbed (42% of total area) (Figure 8 and Figure 9). The seabed loss actions were mainly concentrated in the infralittoral area (below ≈30 m depth), caused by all the activities except fisheries (i.e. prospections, cables, artificial reefs or aquaculture), while seabed disturbed areas were widely distributed from infralittoral to large areas of continental shelf and slope (between 30 and 400 m depth). The results also showed that the SCI of Avilés Canyon System was affected, being the 29% of the total area disturbed.

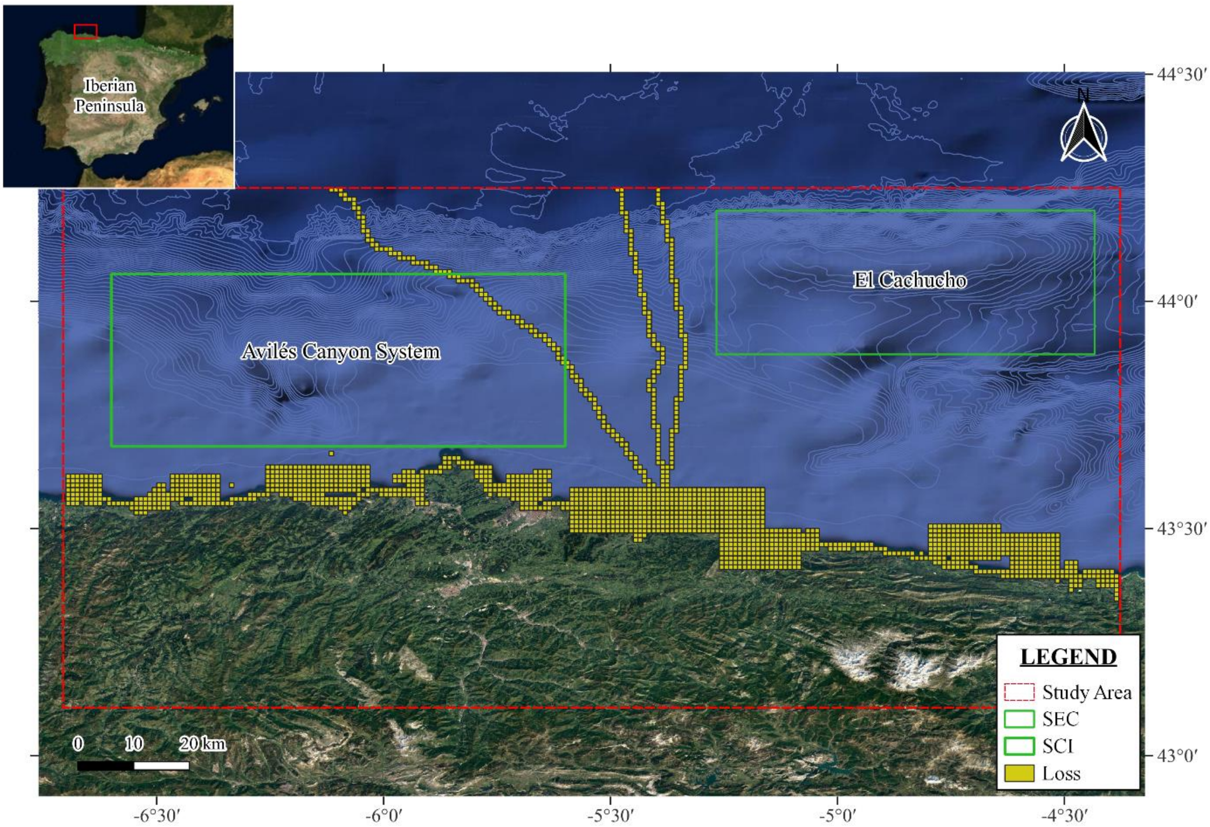


Figure 8. Extend and distribution of the loss area (km^2) over the study area.

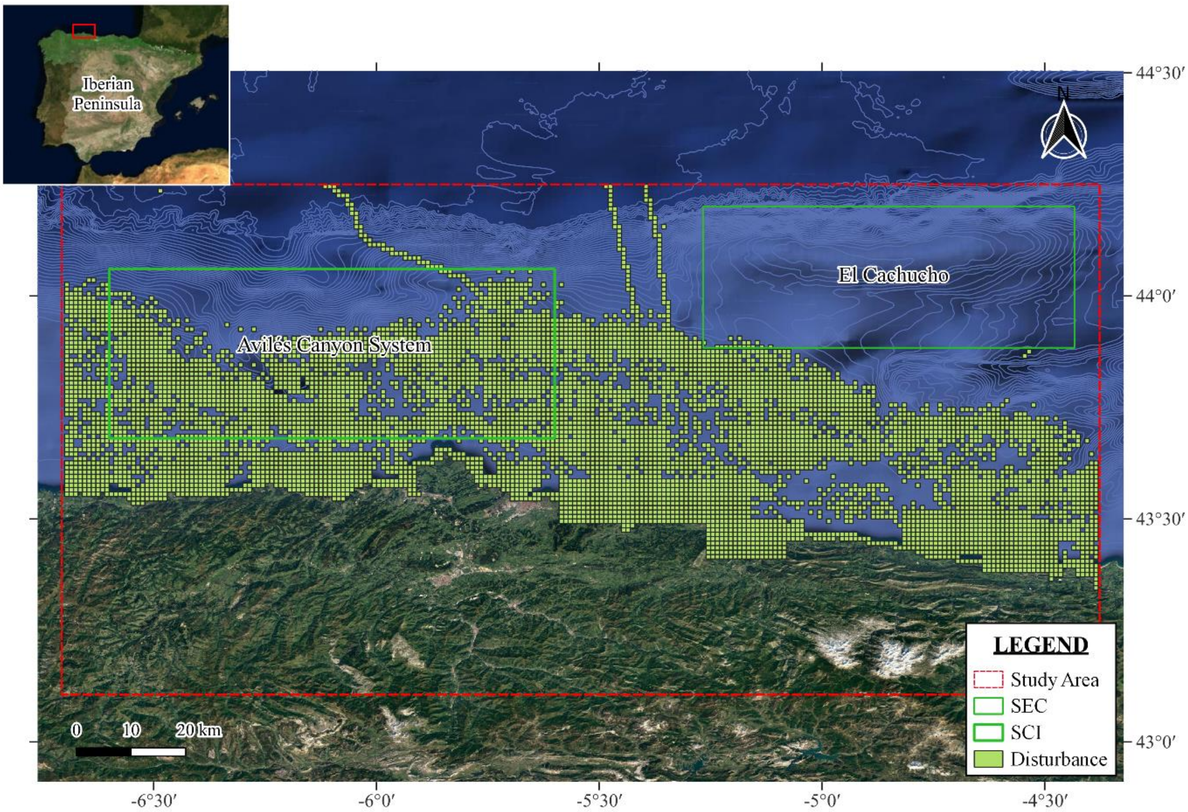


Figure 9. Extend and distribution of the disturbance area (km^2) over the study area.

The results showed that the human activities that are affecting larger surface area are those related to fisheries (Bottom pair trawl, Set longlines, Set gillnets and Bottom otter trawl), with values between 1222,98 km^2 and 3129,75 km^2, followed by artificial reefs (678,56 km^2) and oil & gas prospections (521,84 km^2). Aquaculture activities showed the smallest distribution surface area, with only 5,39 km^2 (Figure 10).

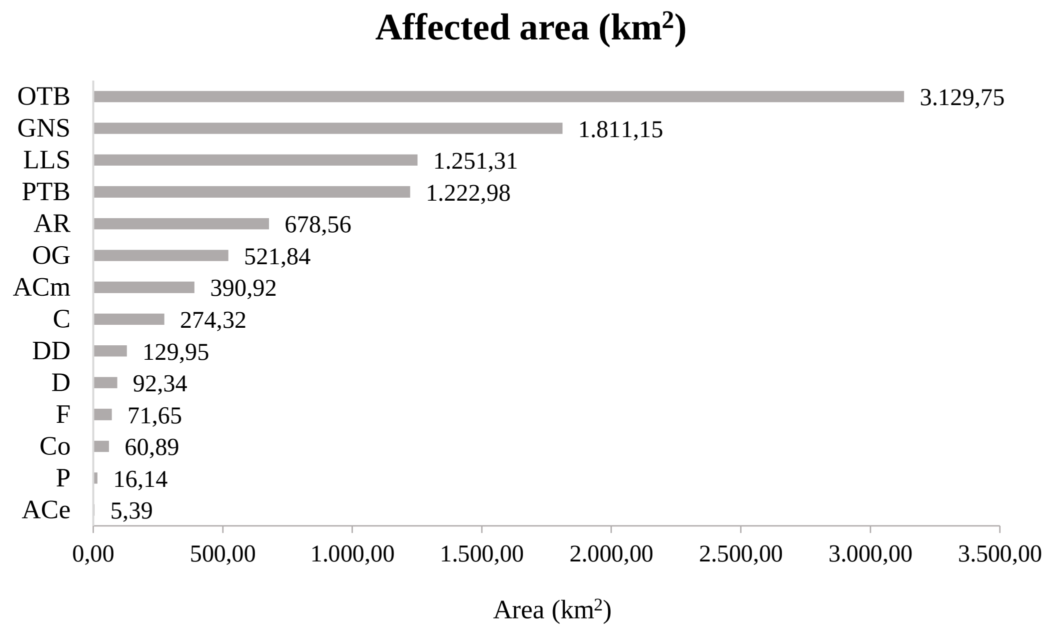


Figure 10. Affected area (km^2) by activities. ACe: Aquaculture establishment. P: Ports. Co: Collapse. F: Anchoring probability. D: Dredge points. DD: Dredging disposal. ACm: Mollusc aquaculture. OG: Oil & Gas extraction points. AR: Artificial reefs. PTB: Bottom pair trawl. LLS: Set longlines. GNS: Set gillnets. OTB: Bottom otter trawl.

The total percentage of area affected (disturbed and lost) per broad habitat type (BHT) is shown in Table 4. The results showed that the Infralittoral habitats (InfMu, InfSa and InfCs) have the most affected areas, with practically 100% of their habitats affected by a pressure. Circalittoral mud (CirMu) also showed the 100% of their seafloor area affected. After those habitats, soft sedimentary bottoms are the most affected ones showing the Offshore circalittoral mud (OfCirMu) and Circalittoral coarse sediment (CirCS) the 83,88% and 77,9% of area affected, respectively. Note that hard substrate habitats, such as Infralittoral rock and biogenic reef (InfRo), Circalittoral rock and biogenic reef (CirRo) and Offshore Circalittoral rock and biogenic reef (OfCirRo), showed more than 70 % of their total area affected (Table 4). The deepest seabed areas (below 600 m depth) showed the lowest area affected, ranging from 18 to 48 % along the upper bathyal and from 2 to 7 % along the lower bathyal habitats.

Table 4. Table showing the number of csquares affected by broad habitat type (BHT), as well as the affected area (km^2 and %). For the % of habitat area affected a color scale has been set up; from red to green to show grading from most affected to lowest affected. The BHT are organized by distance from the coast, from closest to furthest, and by community sensitivity, from lower to higher.

BHT	Number of affected squares	Affected area (km^2)	% Affected
Infralittoral mud	4	3,59	100,00%
Infralittoral sand	91	80,70	98,91%
Infralittoral coarse sediment	1	0,90	100,00%
Infralittoral rock and biogenic reef	158	138,97	86,34%

BHT	Number of affected squares	Affected area (km^2)	% Affected
Circalittoral mud	12	10,75	100,00%
Circalittoral sand	342	303,77	74,67%
Circalittoral mixed sediment	3	2,68	75,00%
Circalittoral coarse sediment	92	80,60	77,97%
Circalittoral rock and biogenic reef	478	420,18	70,92%
Offshore circalittoral mud	307	269,03	83,88%
Offshore circalittoral sand	1529	1323,61	70,56%
Offshore circalittoral mixed sediment	108	96,38	71,52%
Offshore circalittoral coarse sediment	302	267,35	73,66%
Offshore circalittoral rock and biogenic reef	903	779,87	71,55%
Upper bathyal sediment	2004	1699,06	48,89%
Upper bathyal sediment or Upper bathyal rock and biogenic reef	47	41,84	18,08%
Upper bathyal rock and biogenic reef	219	189,95	33,23%
Lower bathyal sediment	75	66,83	6,95%
Lower bathyal sediment or Lower bathyal rock and biogenic reef	55	47,99	5,05%
Lower bathyal rock and biogenic reef	6	5,35	2,73%
Abyssal	72	62,97	1,96%

The number of habitats disturbed by different percentage of affection was also analyzed. As shown in Figure 11, 14 of the studied habitats showed more than the 50% of their area affected by human pressures, while 7 habitats have less than 50% of their area affected. 5 of these habitats showed less than 25% of their area affected, while only two have between 25 and 50% of their distribution area disturbed.

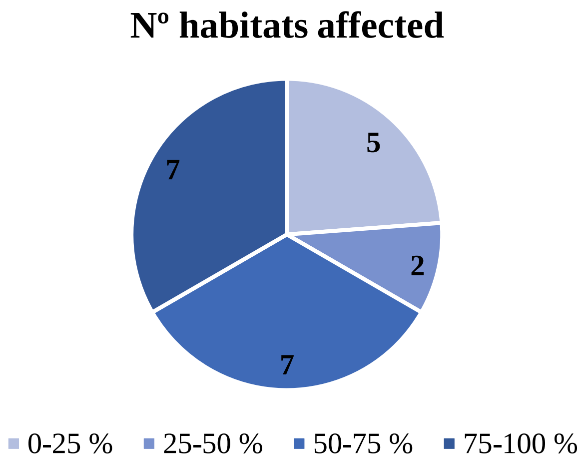


Figure 11. Number of habitats depending on the percentage of their area affected by some pressure. 0-25% of their area affected, 25-50% of their area affected, 50-75% of their area affected and 75-100% of their area affected.

Similarly, the total number of affected csquares has been represented depending on the percentage of affected habitat. Thus, those with more than 75% affected constitute a total of 561 csquares, which together with the 3665 csquares occupied by those habitats with 50-75% affected, represent more than half of the area.

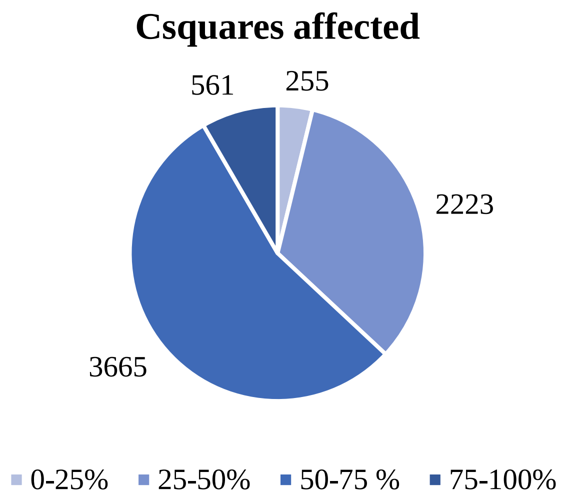
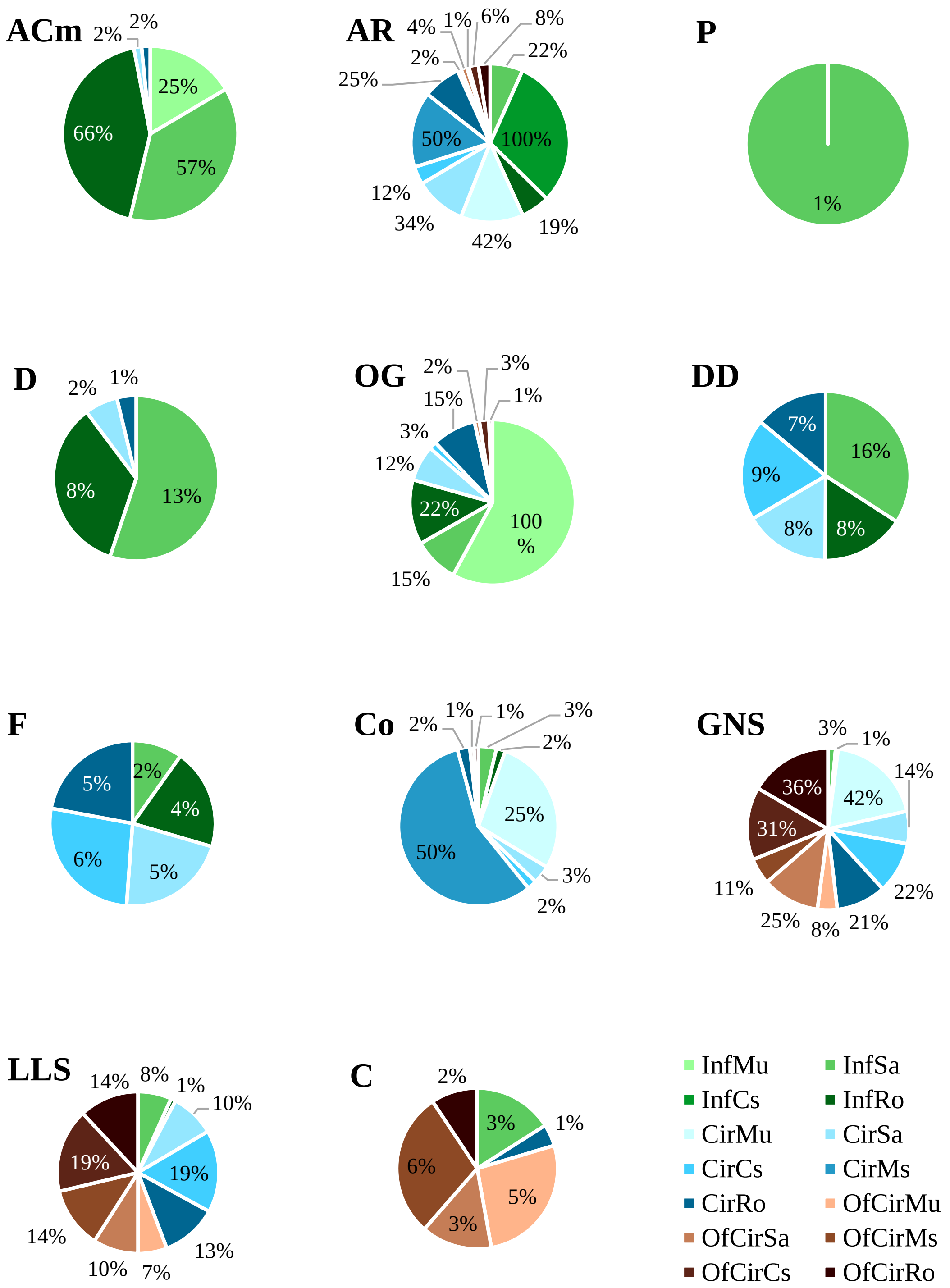


Figure 12. Csquares affected by percentage of affection of the total area occupied by the different habitats. 0-25% of their area affected, 25-50% of their area affected, 50-75% of their area affected and 75-100% of their area affected.

A detailed analysis of the different activities and the extent of their affection per habitats type, of the habitats that are under most pressure (50-100%), is described below (Figure 13). It can be observed that a different distribution of activity occurred depending on the habitats, thus mollusc aquaculture, dredging points, ports and prospections exert pressures mainly in infralittoral (97%, 90%, 100% and 74% respectively), meanwhile cables, set gillnets, set longlines, bottom pair trawls and bottom otter trawls appear mostly in offshore circalittoral (70%, 55%, 56%, 78% and 58% respectively) and collapse and anchoring probability in circalittoral (90% and 70% respectively). It is noteworthy that artificial reefs and dredging disposal sites area similarly distributed either in infralittoral (44% and 50%) or in circalittoral (50% and 50%).

Furthermore, Figure 13 shows the percentage of habitat that is affected by each activity (percentage detailed inside graphics). InfSa and InfRo, showed most of the area affected by mollusc aquaculture (ACm) activity (57% and 66% respectively), followed by artificial reefs (22% and 19%) and oil and gas prospections (15% and 22%). Oil and gas (OG) and artificial reef (AR) activities also showed wide extend along the infralittoral habitats, respectively occupying the 21% and 20% of these habitats. Dredge points (D) and dredge disposal (DD) also showed relevant area of disturbance on InfSa and InfRo areas.



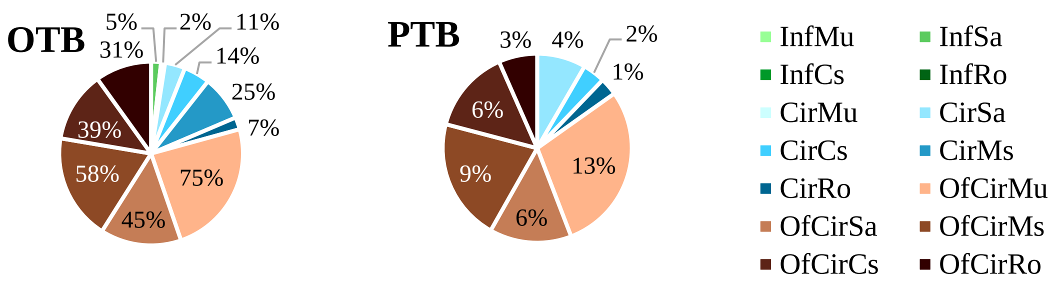


Figure 13. Percentage (%) of habitat type affected by activity. Percentage (%) inside graphics show the percentage of each habitat affected by that activity. ACm: Mollusc Aquaculture. AR: Artificial reef. C: Cables. Co: Collapse. D: Dredging points. DD: Dredging disposal. F: Anchoring probability. P: Ports. OG: Oil & Gas. GNS: Anchoring set gillnets. LLS: Set longlines. PTB: Pair trawls. OTB: otter trawls.

The circalittoral area (between 35 and 60 m depth), similar to infralittoral area, CirSa, CirRo, together with CirCs, are the habitats with the highest overlap of activities (Figure 13). The circalittoral area is mostly affected by the artificial reefs (AR) and different types of fisheries. AR is affecting between 12% and 50%, OTB between 7% and 25%, GNS between 14% and 42% and LLS between 10% and 19%. The extension of oil and gas (OG) activities also overlaps with CirSa and CirRo habitats, with 12% and 15% respectively. Also dredging disposal (DD) is present in CirCs habitats.

For the offshore circalittoral habitats the number of activities affecting each type of habitat is also high (Figure 13). At these depths (112-645 m depth) fishing is the most represented activity, being always the most relevant activity, affecting the largest seabed area, specifically OTB is the fishing activity affecting the largest area, between 31% and 75%. After this, in most habitats it is GNS the fishing gear affecting the second largest area (8% to 36%), while LLS and PTB affects the smallest areas.

4.3. Cumulative pressures analysis

In order to analyze the pressures in more detail, Table 5 shows the matrix of interaction between activities, showing which activities have a greater area of overlapping. The results showed that the four different bottom fisheries analyzed (i.e. GNS, PTB, OTB and LLS) have the greatest overlap between them, with values between 173,92 km^2 and 920,58 km^2. Attending to the other activities, it should be highlighted the moderate overlapping between oil and gas prospections and mollusc aquaculture (81,59 km^2). For fishing activity taking place in the same space as other activities, bottom otter trawls interact with cables 99,07 km^2, while set gillnets overlaps with artificial reefs and oil and gas prospections in 61,84 km^2 and 65,41 km^2, respectively.

Even though fishing has the largest area of affection within the study area, it does not showed overlap with most of the activities exerting pressures. In addition, aquaculture, one of the activities with a lower occupancy, only coincide in space with mollusc aquaculture and dredging sites.

Table 5. Interaction matrix between activities by surface area (km²). From green to red to represent from lower to higher area of interaction.

	Aquaculture Sites (ACe)	Molusc Aquaculture (ACm)	Artificial Reef (AR)	Cables (C)	Dredge Points (D)	Collapse (Co)	Oil & Gas (OG)	Anchoring Probability (F)	Ports (P)	Dredge Disposal (DD)	Bottom Otter Trawls (OTB)	Set Longlines (LLS)	Set gillnets (anchored) (GNS)	Bottom Pair Trawls (PTB)
Aquaculture Sites (ACe)														
Molusc Aquaculture (ACm)	5,39													
Artificial Reef (AR)	0	79,80												
Cables (C)	0	4,48	0											
Dredge Points (D)	2,69	59,17	12,54	0										
Collapse (Co)	0	15,23	42,99	0	7,17									
Oil & Gas (OG)	0	81,59	0	11,65	8,07	0								
Anchoring Probability (F)	0	24,19	3,58	0	14,34	5,38	7,17							
Ports (P)	0	13,44	1,79	0	8,07	0,90	1,79	1,79						
Dredge Disposal (DD)	0	40,34	34,95	3,58	29,59	0	15,24	15,23	3,59					

	Aquaculture Sites (ACe)	Molusc Aquaculture (ACm)	Artificial Reef (AR)	Cables (C)	Dredge Points (D)	Collapse (Co)	Oil & Gas (OG)	Anchoring Probability (F)	Ports (P)	Dredge Disposal (DD)	Bottom Otter Trawls (OTB)	Set Longlines (LLS)	Set gillnets (anchored) (GNS)	Bottom Pair Trawls (PTB)
Bottom Otter Trawls (OTB)	0	0,90	19,74	99,07	0	0	18,81	8,95	0	4,48				
Set Longlines (LLS)	0	0	78,88	8,03	0	6,26	39,42	4,48	0	4,48	419,95			
Set gillnets (anchored) (GNS)	0	1,79	98,56	14,32	0	1,79	65,41	5,37	0	3,58	498,51	427,39		
Bottom Pair Trawls (PTB)	0	0,90	0	32,99	0,90	0	0	4,48	0	4,48	920,58	173,92	175,74	

The results of cumulative pressure analysis showed that most of the total study area is affected by only one pressure exerted by activities (either loss or disturbance), specifically 3031,5 km^2 (20% of the total study area), while 2567,3 km^2 are affected by 2 pressures (17%), whereas 872,2 km^2 (6%) are affected by 3 or 4 pressures (Figure 14). Finally, a total of 86 km^2 (1%) are affected by 5 or more pressures, with up to 10 pressures accumulating in one csquare.

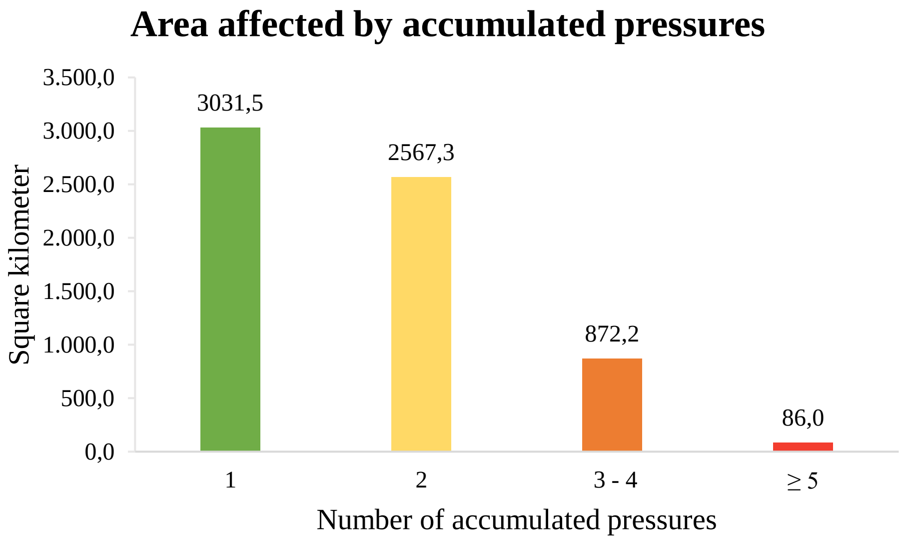


Figure 14. Area (km^2) affected depending on the number of accumulated pressures. The accumulated pressures can be loss or disturbance from different activities occurring in the same csquare. Green: those csquares where one pressure is occurring. Yellow: those csquares where two pressures are occurring. Orange: those csquares where three or four pressures are occurring. Red: those csquares where five or more pressures are occurring.

Figure 15 shows the distribution of the analyzed accumulated pressures in space. The highest accumulation of pressures occurs in coastal areas, where highest number of csquares with 2, 3-4 and ≥5 pressures were found. The results also showed the presences of 2 and 3-4 accumulated pressures along the continental slope (200-400 m depth), while along the continental shelf (50-200 m depth) most of the csquares were occupied by 1 pressure. It is important to mention that the Site of Community Importance (SCI) of Avilés Canyon System is highly pressured with up to a total of 4 pressures overlapping in the space, while inside the El Cachucho Special Area of Conservation, pressures were limited to a small area, being affected only by a pressure at time at its southern limit.

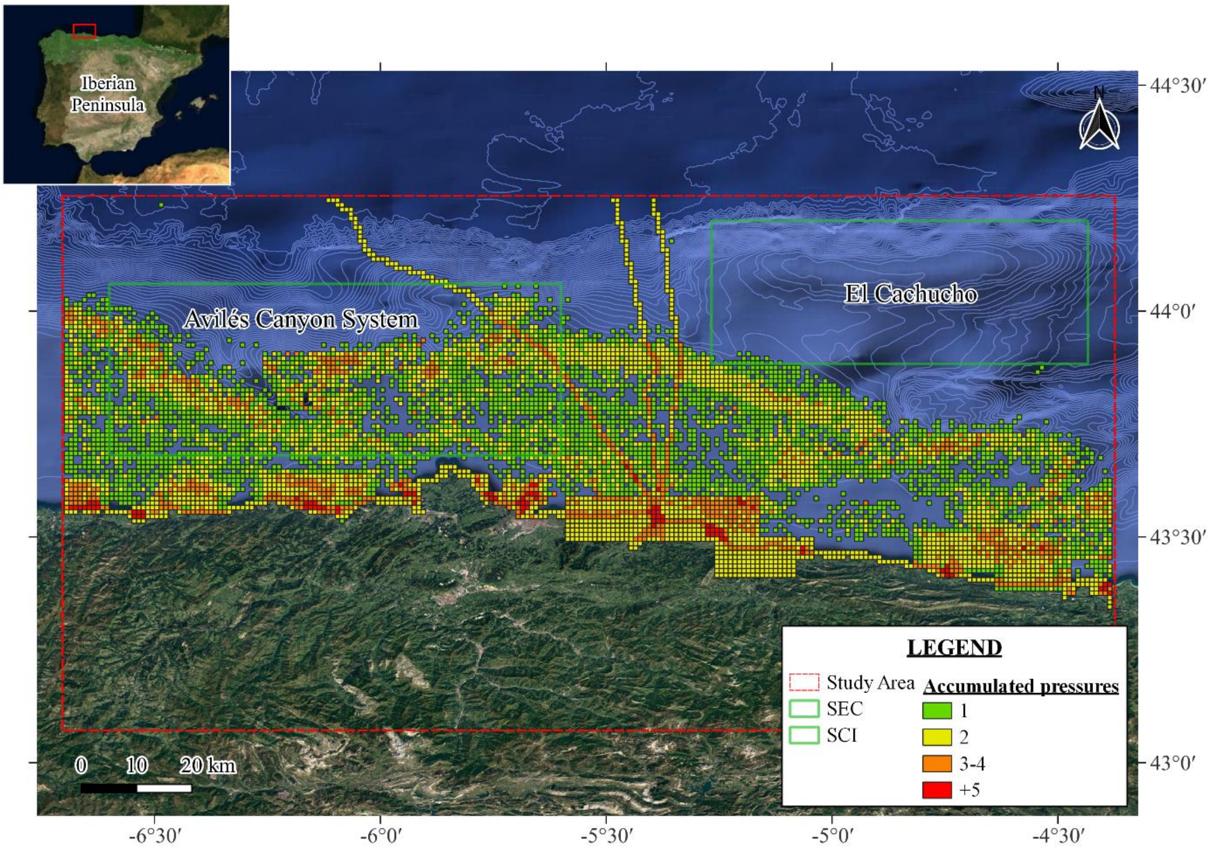


Figure 15. Accumulated pressures map. The accumulated pressures can be loss or disturbance from different activities occurring in the same csquare. Green: those csquares where one pressure is occurring. Yellow: those csquares where two pressures are occurring. Orange: those csquares where three or four pressures are occurring. Red: those csquares where five or more pressures are occurring.

The accumulated pressures were also analyzed by the habitats affected (Figure 16). As in the previous section, the infralittoral, circalittoral and offshore circalittoral habitats were analyzed, of which all the habitat types were affected.

We found different accumulative pressures patterns depending on the habitats. Attending to the infralittoral habitats (0 to 15 m depth), they showed the largest affected area having 2 pressures at the same time (0,9 to 58,29 km^2), followed by those csquares where there were 3-4 (0,9 to 60,07 km^2) pressures accumulated. InfSa and InfRo have the greatest pressure accumulation, with 15% and 10% of the habitat area affected by 5 or more pressures (Figure 16). Whereas offshore circalittoral habitat (between 113 and 644 m depth) has a large area affected (2814,9 km^2) but by fewer pressures. Here, the greatest accumulation occurs again in the OfCirSa and OfCirRo, with 4,48 and 2,69 km^2 respectively affected by 5 or more pressures.

Between the two previous habitats described it is the circalittoral, which showed an intermediate dynamic (Figure 16). The greatest area is affected by 2-4 pressures, occupying

543,87 km^2 of 830,52 km^2 (65%), followed by the affection of one pressure (32%) and barely affected by 5 or more (3%).

It is important to notice the large accumulation of pressures on rock habitats throughout the analyzed depth range (26,89 km^2), specifically 59% of the total area affected by 5 or more pressures, both in shallow (0-15 m depth) and deep (up to 644 m depth) areas. Similarly sandy habitats have 27,79 km^2 affected by 5 or more pressures (61%).

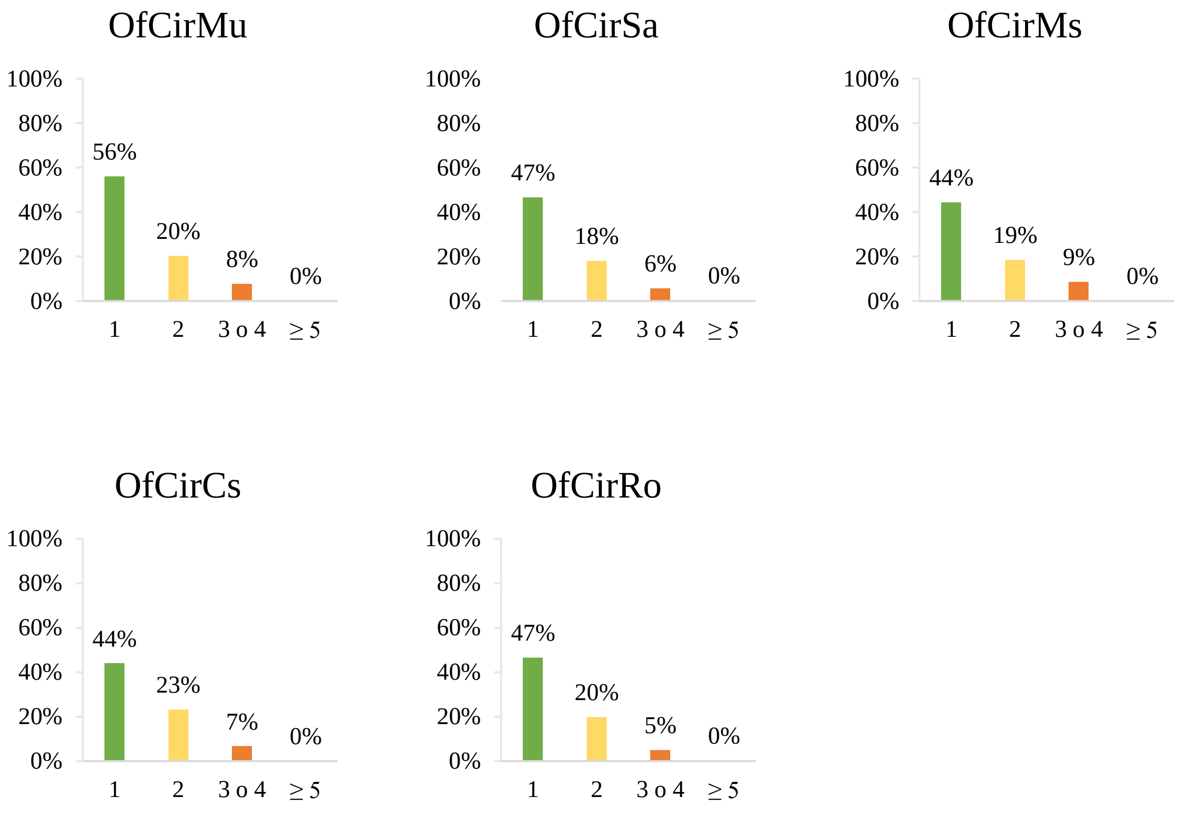


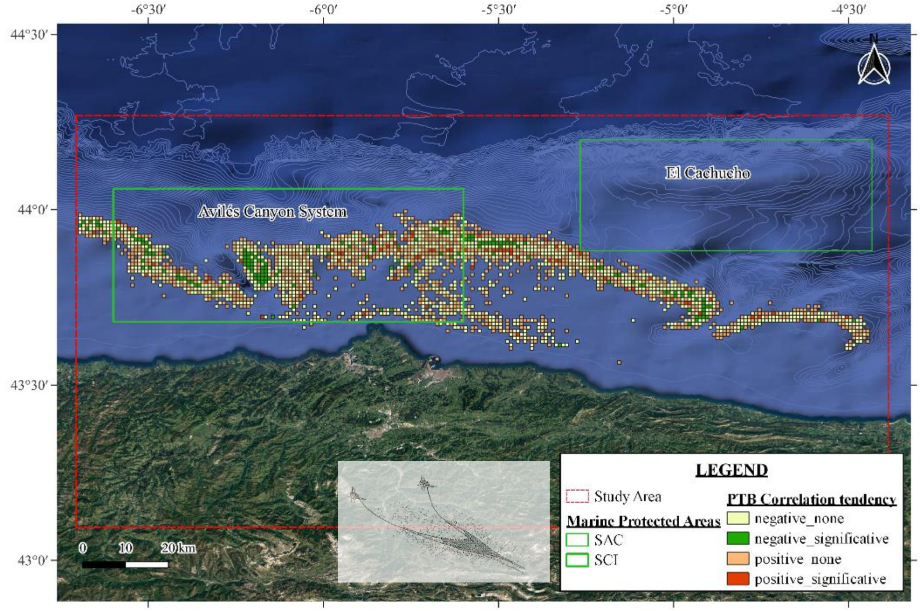
Figure 16. Percentage (%) of affected BHT by different number of accumulated pressures. Percentage has been calculated with respect to the total area of each habitat. Green: those csquares where one pressure is occurring. Yellow: those csquares where two pressures are occurring. Orange: those csquares where three or four pressures are occurring. Red: those csquares where five or more pressures are occurring.

4.4. Spatiotemporal variation of cumulative fisheries pressures

Finally, the spatiotemporal analysis of fishing intensity by gear type was carried out. For this purpose, the tendency of coefficient value resulting from the multiple linear regression models for fishing intensity (hour/ km^2), by cell grid and over the years (2009-2021) were mapped and are shown in Figure 17 and Figure 18.

The resulting maps showed a different trend depending on the fishing gear in the Central Cantabrian Sea. Thus, static fishing gears, such as LLS and GNS showed a positive trend in most areas, while mobile bottom fishing gears (OTB and PTB) showed a negative trend along the study area. The negative trend of mobile gears was higher for OTB, where 53% of the csquares showed a negative coefficient value (13% of these significant), while in the case of PTB the negative values were observed in 36% of the csquares, of which 5% show a significant negative trend. On the other hand, although static gears showed a higher percentage of positive trends, the observed difference was not very large, with 35% positive versus 32% negative observed for LLS and 40% versus 35% for GNS. Furthermore, it should be noted that only 3% (LLS) and 4% (GNS) of the csquares showed a significant positive trend.

Special attention should be given to the area of the Avilés Canyon System, since while the mobile gears showed wide areas with a significant negative trend (Figure 17), the static gears showed a positive trend, even significant in certain locations, especially for LLS (Figure 18).



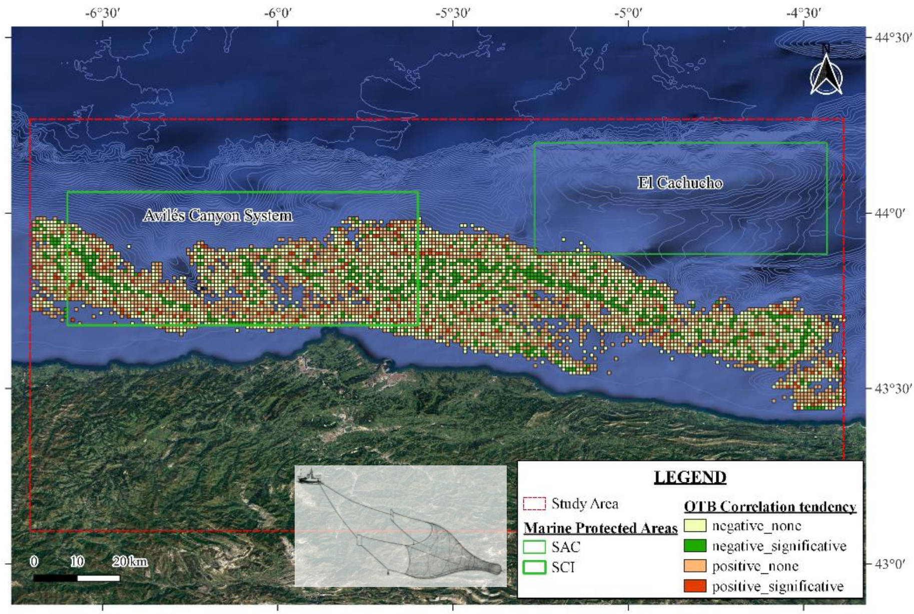


Figure 17. Spatial correlation tendency by mobile bottom gears. Left: Bottom Pair Trawls (PTB), computer graphics retrieved from: Grieve et al., 2014. Right: Bottom Otter Trawl (OTB), computer graphics retrieved from: Ravasio, 2022. Significant when $p<0,1$.

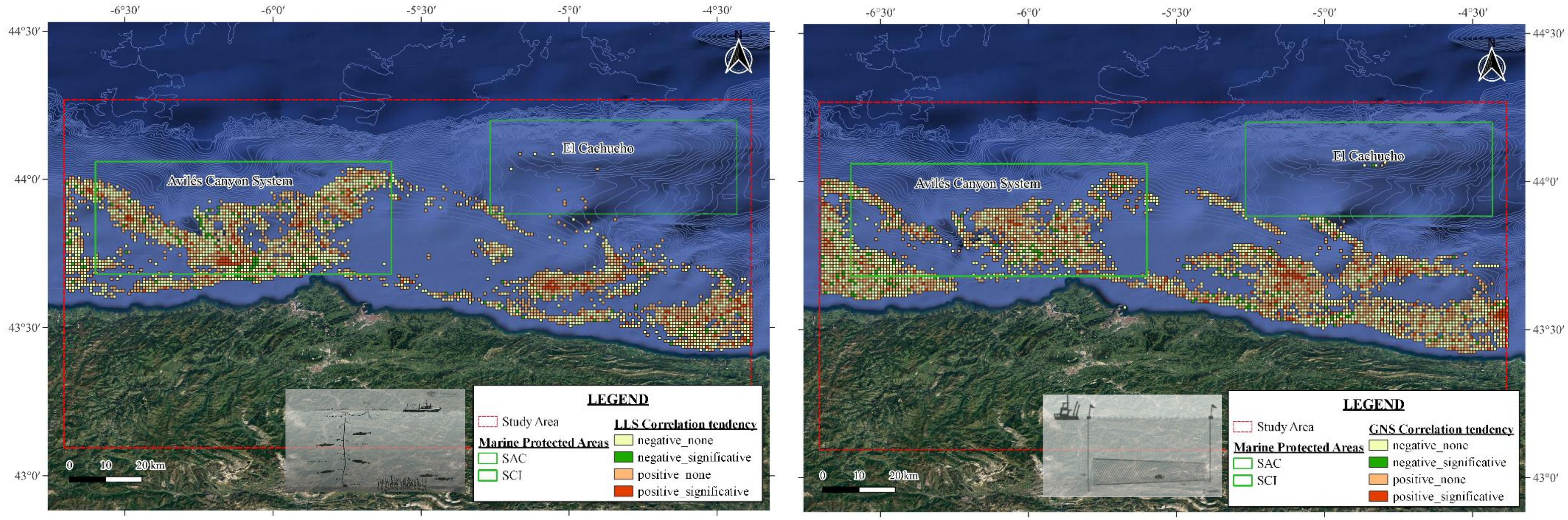


Figure 18. Spatial correlation tendency of static bottom gears. Left: Set Longlines (LLS), computer graphics modified from: Fisheries Research and Development Corporation (FRDC), s.f. Right: Set Gillnets (GNS), computer graphics modified from: Office of Protected Resources, 2021. Significant when *p<0,1*.

5. DISCUSSION

5.1. Human activities distribution and cumulative pressures analysis

This study analyzed the extent and distribution of the different human activities affecting the North Atlantic Demarcation, giving a particular emphasis to the sea floor integrity along the Central Cantabrian Sea, and all developed within the framework of Marine Strategy Framework Directive (MSFD) (EC, 2008). We analyzed 17 human activities for the North Atlantic Demarcation, which exert different types of pressures in the seabed, with those of a biological nature and those that introduce substances into the environment having the largest areas of influence. In this study, we have selected the activities that exert a direct physical impact in the seabed, either habitat loss or disturbance, which have a much smaller area of influence (1-5 km), although they usually have a local influence (Fernandes et al. 2020).

Our results showed that the Central Cantabrian Sea is highly impacted. The Central Cantabrian Sea have 6556,13 km^2 of the area disturbed and 1617,18 km^2 of the area lost, respectively representing the 42% and 10% of the total area studied, being almost half of the study area affected by 1 pressure. Similarly, studies conducted in other areas, such as England or Canada, showed around half of the area impacted (Ban et al., 2010; Foden et al., 2010). The habitat loss, those areas that imply permanent changes to the seabed, was found predominantly in the coastal zone, while the disturbed areas were also present in waters with higher bathymetries ranges (100 to 1000 m depth). Foden et al. (2011) similarly showed for UK waters that the area affected by seabed disturbance is larger than that where seabed loss occurs.

The characterization of activities in the North Atlantic Demarcation conducted by the EsMarEs group in 2019 establishes commercial anchoring, the installation of infrastructures, sediment extraction and the creation of artificial beaches as the activities with the largest surface area affected (MITERD, 2019a). From all the activities analyzed in this study, bottom fishing was the most prevalent activity that exert habitat disturbance in the study area with a total of 7415,19 km^2 affected, with bottom otter trawl (OTB) occupying the largest area (3129,75 km^2), followed by set gillnet (GNS) area (1811,19 km^2). There are many studies focused on the study of fishing as the main human impact activities around the world (Eigaard et al., 2017; Hintzen et al., 2021). Among others, Ferrà et al. (2017), Foden et al. (2011), Hammar et al. (2020) and Link et al. (2002) highlight the importance of trawling as a source of pressure on the ecosystem, such as abrasion, smothering or extraction. This activity is widely distributed, leading to disturbance of the seabed, so it would be expected to be the activity that contributes most to the impact on the marine areas assessment (ICES, 2016).

Additionally, we found high overlap between different fishing activities, which occurs mainly over sedimentary habitats. Already Andersen et al. (2020) showed the importance of fisheries in North Sea and the Baltic Sea, where a large part of its bottom fisheries contributed to the seabed impact compared to other factors affecting the seabed (around 10%). In the Mediterranean Sea fishing is also the most impacting pressure, as well as along the Portuguese coast where it is one of the most significant pressures, with extend area values from 10% to 64% of area affected by fisheries (Batista et al., 2014; Micheli et al., 2013). Bottom pair trawls (PTB) and bottom otter trawls (OTB) are those activities with the highest overlapped area affected (920,58 km^2), these results being in agreement with previous studies conducted in the Cantabrian Sea (Punzón et al., 2016). Static gears such as gillnet and longlines, also showed high overlap in their working areas, sharing fishing grounds, such as those located inside the SCI of Avilés Canyon. Punzón et al. (2016) also identifies for the SCI of Avilés Canyon System a lesser overlap between mobile and static gears than between them. This type of analysis is of great relevance taking into account the implementation of the future management plan. The management of these resources must be done in a sustainable way to ensure the maintenance of good environmental status including an equilibrium between human economic health well-being and environment well-being.

Despite the overlap between activities and the physical pressures they exert, especially fishing gears, the results shows that the largest area in the Central Cantabrian Sea is affected by only 1 pressure (3031,5 km^2; 20%), but closely followed by the accumulation of 2 pressures, with 2567,3 km^2 (17%) of the area affected. Foden et al. (2011) in England show that of the total area affected by pressures, a small fraction (< 0,1%) is pressured by 2 to 4 at the same time, in contrast to the dynamics of the present work. The observed accumulation of pressures may be due to the spatial overlapping of the different fisheries gears in the deeper areas, while in the coastal areas the overlapping might be caused by a diversity of activities affecting the seabed (i.e. anchoring, aquaculture, ports, dredging sites, etc.). Then, as the bathymetry increases, there is a succession of impact-generating activities, from a greater presence of activities with a more limited distribution, such as aquaculture, dredging points, oil & gas prospection or artificial reefs, to the different fisheries gears. Similarly, Kenny et al. (2018) showed this distribution for activities and their associated pressures for the North Sea.

The highest accumulation of pressures is found in the coastal zone, where a large number of activities converge in a smaller area (7% for more than 3 overlapping pressures), similarly to the trend observed in other European areas (Micheli et al., 2013), or even in the world (Ban et al., 2010; Halpern et al., 2009). Bevilacqua et al. (2018) also obtained a great presence of more than 4 cumulative pressures in the Italian coastline. Although, these authors include also other type of pressures such as contamination and ocean acidification. The accumulation of pressures reflects that littoral and shelf habitat, such as infralittoral, circalittoral and offshore circalittoral habitats, are affected to a greater extent. Despite this, a large spatial variation in cumulative pressures can be found (Hammar et al., 2020), with waters as the English ones with a greater overlap between bottom loss and disturbance (Eastwood et al., 2007), making this type of analysis very necessary for marine spatial planning, in order to determine the most affected areas.

It is necessary to mention that for the present work the pressures that generate loss of seabed have been accumulated in order to know the number of activities introducing pressures in the system and thus be able to conduct a complete overview of the state of the ecosystems. However, for the future analysis on the state of seabed habitats, the presence of a single pressures generating seabed loss should be enough, since one activity exerting loss introduces the greatest degree of impact associated with the pressure, therefore adding more than one pressure generating loss, would not increase the impact (ICES, 2019a).

Of the 21 broad habitat types (BHT) present in the study area, 14 are affected in more than 50% (4226 km^2). As above stated, of these habitats, the infralittoral, the circalittoral and the offshore circalittoral ones, located between 0-644 m depth, were the habitats with the highest percentages of affection. These habitats showed more than 70% of the total affected habitat occupied by, at least, one pressure, with the percentage of affection of the infralittoral being close to 100%. This trend has been observed by many other authors, such as Ban et al. (2010), Batista et al. (2014), Halpern et al. (2008) or Stelzenmüller et al. (2010). In this way, the coastal area showed the highest accumulation of pressures, with the 86% of the infralittoral habitats being found to be disturbed and 91% lost. These values decrease with depth, occurring a 10% of loss and 71% of disturbance in offshore circalittoral. Although the number of pressures overlapping decrease, we found that the distribution and extend of the pressures increases, what is mainly due to the high presences of fishing below the 50 m depths. Helsinki Commission (HELCOM) (2010a) establishes for Baltic Sea Waters the loss of seabed in coastal areas, while disturbance appears more dispersed on the wide seabed, as verified by

Korpinen et al. (2013), and the same trend is observed for the English waters (Eastwood et al., 2007).

Despite the different distribution of activities, soft bottoms are the most affected habitats along the entire bathymetric range, with values of 99% for the Infralittoral sand, 74% for the Circalittoral sand and 71% for the Offshore circalittoral sand. This has not only been observed in activities that cause physical damage to the seabed (Forden et al., 2011; Kenny et al., 2018), but by many others such as agriculture, population or industrial effluents (Holon et al., 2020). Specifically, in the present work, all types of activities have been found on soft bottoms (i.e. dredging points, artificial reefs or otter trawls), according to the described differentiation by bathymetry.

The habitats where high pressure accumulation occurs are not limited to soft bottoms, as presented by Foden et al. (2011). In addition to sand and mud, hard substrate habitats such as coarse sediment and rock and biogenic reef are found to be affected by a high number of accumulated pressures (applied by different number of activities), highlighting the high number of pressures found on the Infralitttoral rock and biogenic reef habitats, with up to 9 accumulated pressures. As described by Halpern et al. (2009), for soft ecosystems, due to the potential low sensitivity, a large accumulation of pressures may not be correlated with a high degree of impact. However, for more sensible habitats such as rocky habitats, the accumulation of pressures easily results in a high degree of impact (Halpern et al., 2009).

Benthic habitats are the main components of seabed ecosystems, being the most relevant in terms of sensibility the biogenic habitats (De la Torriente et al., 2020). These habitat-forming species are widely distributed and are extremely variable throughout Spanish waters, which allows a great richness and diversity to develop in them (Templado et al., 2009; Victorero et al., 2018). The introduction on the ecosystem of human pressures produces changes on the composition and function of these sensible habitats (González-Irusta et al., 2018; Serrano et al., 2022). As reflected by De la Torriente et al. (2022), since these biogenic habitats are not subject to natural disturbances, their resilience is lower than those that are naturally disturbed, and the same is valid for degraded habitats. Studies such as the one carried out by Giménez-Casalduero et al. (2018), reflected the large number of threats to which they are subjected, as well as their conservation status. In the present study, rocky areas are 43% affected, mostly associated with aquaculture, artificial reefs and prospection in most coastal areas and fishing activities at higher bathymetric heights. Bevilacqua et al. (2018) found that increasing pressure levels generate a clear shift from habitat-forming ecosystems to assemblages dominated by turf-forming algae, leading to a decrease in diversity. Given the relevance of these habitats, determining the sensitivity of these habitats to each pressure and the extent of the habitats affected by a pressure and pressure accumulation is very important, so that adversely and non-adversely affected areas should be modelled and mapped in the near future.

5.2. Spatiotemporal series of fisheries

Finally, due to the high relevance of fishing distribution and the potential impact of this activity in the area (Punzón et al., 2016), we also analyzed the spatiotemporal trend of these activities along the Central Cantabrian Sea. For this study, the spatiotemporal analysis could only be conducted for fishing pressure due to the lack of intensity time series data for the other human activities analyzed. However, for the rest of the activities, work is ongoing to collect this type of data, such as the volume (m^3) for dredging and dumping point, in order to provide the temporality of these impacts (Elliott et al., 2020; MITERD, 2019b).

Our analysis showed different temporal tendency depending on the fishery gear. The static gears, such as LLS and GNS, showed a general increase intensity along time, with 35% and 42% of the area showing positive trend for LLS and GNS, respectively. Mobile fishing gears in contrast, showed a general negative trend, with 53% (OTB) and 36% (PTB) of the area showing a decreasing trend of the fishing intensity over time. Halpern et al. (2015) described a negative significant trend in many European countries, however, studies conducted at a more local level show a large variability over the years, although with a low spatial variation (Bellman et al., 2005; Larcombe et al., 2001; Stelzenmüller et al., 2008). The fact that the distribution pattern of fishing activities does not vary over time in other areas (Foden et al., 2010), reinforces the urgency of carrying out analyses of the degree of impact to which seabed habitats are subjected, especially in protected areas. Besides that, due to the more limited distribution of most activities, it can be expected that in areas where fishing is not so important, the temporal variation will not be as relevant (Foden et al., 2011).

In relation to fishing, special attention should be paid to the marine protected areas in the study area. While the Special Area of Conservation (SAC) El Cachucho does not shows any pressure on the seabed (1%), the Site of Community Importance (SCI) of Avilés Canyons System is highly impacted (29% of the total area was disturbed and 2% of it was lost), disturbance being almost exclusively produced by fishing activity.

The strong fishing pressured areas need spatial management of activities, so that they are distributed throughout the space and thus avoid, as much as possible, the accumulation of these activities (Punzón et al., 2016). To address this in Spain, the LIFE + INDEMARES Project, created in 2014 with the aim of contributing to the protection and sustainable use of Spain seas, is developing a management plan to reduce the impact on ecosystems (Sánchez et al., 2014).

5.3. Limitations and possible solutions

Despite the usefulness of characterizing activities and pressures and their interaction with seabed habitats for marine spatial planning (Ban et al., 2010), there are several assumptions that have been made in this study due to the lack of knowledge and data limitations that need to be discussed and improved in the future. Here we cited the most relevant points:

(a) The total area that generates the potential impact of each activity was calculated based on the entire area established for the activity and its zone of influence.

In the present work, according to the georeferenced method developed by Rees (2013), a grid with csquare 0.01 (1 km^2) has been generated. For the analyses, although the location of the activities did not occupy the entire csquare, the pressure was associated with the entire square kilometer. Thus, as reflected by Halpern & Fujita (2013), establishing a uniform distribution of pressure in the csquare can lead to under or overestimation of impact. This assumption is difficult to resolve, since, as in any region of the world (Ban et al., 2010), there are many gaps in the information collected (Holon et al., 2015), as well as a lack of studies to establish more concretely the degree of impact (Halpern at al., 2008; Holon et al., 2015; Micheli et al., 2013). According to Giakoumi et al. (2013), detailed spatial data collection is necessary to establish threats and actions to control them, as the location of activities is often approximate (Gobert et al., 2009; Deter et al., 2012). However, most of the data collected for the North-East Atlantic region are located in the North Sea and Celtic Seas, with very little collected for the waters of the North Atlantic region (Dailianis et al., 2018). While some authors, such as Kellon & Arvai (2011), argue that those analyses should not be conducted when key information is missing, they can identify these gaps and redirect governmental efforts towards them (Halpern & Fujita, 2013). It is the case of the analyses carried out at the present work, which intends to provide information on the distribution of pressures and may serve to set overall priorities.

For future analysis it would be necessary to analyses the pressures exerting impacts on the seabed in more detail, specifying the area of the csquare that the activity is occupying and the weight of the pressure depending on the distance from the point of origin, as has been done in other papers, such as the ones recently conducted by Hammar et al. (2020) or Holon et al. (2020).

(b) The intensity of the pressure has only been analyzed for fishing. Thus, we have assumed that the potential impact has the same degree over the entire area where the activity occurs and its zone of influence.

In order to make this approach more accurate, we intend to quantify the pressure associated with the different activities by collecting intensity data such as those collected for fishing (hour/km^2), similar to the methodology applied in the paper of Bevilacqua et al. (2018). In this way, it will be possible to standardize the intensity for the pressures carried out by different activities and to establish the cumulative impact on seabed habitats. Furthermore, the temporal analyses of pressures will contribute to improving knowledge about trends in the accumulation of pressures, which is why future analyses including habitats and other activities will be necessary in order to model future uses and impacts of different pressures in the seabed.

To address these limitations, Judd et al. (2015) propose a series of procedures to establish the cumulative effects of pressures, for which a comprehensive inventory of potential pressures is essential.

5.4. Future assessment

The objective of MSFD for the Descriptor 6 (D6) is to establish the degree of impact produced by the different pressures. In this sense, pressures are the mechanisms through which an activity can have an effect on ecosystems, while impact is the adverse change to the ecosystem (ICES, 2019b; Serrano et al., 2022). To establish the degree of habitats impact it is necessary to establish the degree of sensitivity to each pressure, which has been determined to date by qualitative scoring, according to expert opinion (Halpern et al., 2009; Hammar et al., 2020; Korpinen et al., 2013) and by the developing of quantitative indicators for some pressures (Serrano et al., 2022).

The analysis of the potential impact of pressures on seabed habitats presented in this paper is a step forward to contribute to achieve criteria 4, 5 and 6 of D6 of the MSFD (EC, 2017b). From the basis presented here, efforts to determine the pressure index in the study area, and at a larger scale in the North Atlantic Demarcation, can be directed towards those pressures that are most relevant, by compiling finer scale cartography of those activities which cause a grater affection. A clear example is artificial reefs, since according to the literature, their presence causes a disturbance and loss of the seabed (Andersen et al., 2013; Fernandes et al., 2020; Hammar et al., 2020), which is highly relevant in the coastal areas of the study area. However, studies such as those carried out by Pipitone et al. (2000) or Serrano et al. (2011) found a positive effect of the establishment of these structures on biodiversity in the long term, making it necessary to characterize these infrastructures and their effects in detail. Once this information has been compiled, it is necessary to establish the degree of sensitivity of habitats to different pressures for the waters of the North Atlantic area, using expert judgment, as has been done for waters of the HELCOM area (HELCOM, 2010a, b) or the Californian current (Neslo et al., 2008; Teck et al., 2010), or in a better way developing quantitative index based on the pressure intensity and habitat sensitivity (Elliott et al., 2018; Serrano et al., 2022).

By determining the most affected areas and calculating the pressure index to which the ecosystems are subjected, marine spatial planning based on ecosystems can be carried out more accurately. This analysis will support the correct conservation of protected areas such as the SCI Avilés Canyons Systems, allowing the conservation of marine areas and the sustainable exploitation of current and future resources, such as those proposed in the Spanish maritime spatial plans, which present a potential future use for offshore wind and aquaculture in the study area (Centro de Estudios de Puertos y Costas (CEPYC) & Centro de Estudios y Experimentación de Obras Públicas (CEDEX), 2021).

Cumulative impact maps, as well as the determination of the level of impact to which seabed habitats are subjected, is essential to provide a basis for maritime spatial planning, with the aim of reducing human-generated pressures and achieve the GES (Bevilacqua et al., 2018; Depellegrin et al., 2017).

6. CONCLUSIONS

- Central Cantabrian Sea is highly impacted by human activities. In total the 10% of the area is lost and 42% disturbed. Habitat loss is being practically limited to the coast, while disturbance is the most prevalent impact in the whole study area.
- 14 of the 21 studied habitats showed more than the 50% of their area affected by human pressures. The infralittoral, circalittoral and offshore circalittoral habitats are the most affected habitats, with the highest accumulated pressures occurring in the infralittoral sand and infralittoral rock and biogenic reef habitats
- There is a differentiation between the human activities accumulating in the coastal areas and offshore areas; infralittoral is occupied by high diversity of local human activities such as ports, dredging point and mollusc aquaculture among others, while continental slopes are mostly impacted by bottom fishing.
- Bottom otter trawling is the activity that exerts most pressure on the seabed, especially on sedimentary seabed.
- Along the most affected habitats, the rocky seabed showed 87%, 71% and 72% of their area affected (138,97 km^2, 420,18 km^2 and 779,87 km^2). Due to the potential high sensitivity of these habitats, it should be characterized by habitat-building sensible species, and urgent management measurements are needed.
- The SCI of Avilés Canyon System showed 29% of the area impacted by at least one pressure. These results are relevant for the future management plans that are now in construction in the framework of INDEMARES project. In contrast, in the SAC El Cachucho, located in offshore areas, fishing activities are the unique ones exerting little pressure on the area.
- There are different temporal trends between the fishing gears analyzed. Static gear (LLS and GNS) showed a general increase, while mobile gears (PTB and OTB) showed general decrease trend over time.
- The present work serves as a basis for establishing the pressure index in the North Atlantic Demarcation, adapted from Halpern et al. (2008; 2009) and following the footsteps of others such as Anderson et al. (2013).
- Determining the extend, distribution and accumulation of pressures in the study area will helps to develop future ecosystem-based management plans. In the future, analyses including the intensity and temporality of pressures will have to be developed in order to address the criteria set out in the MSFD and achievement of GES

- In this sense, it is necessary to establish the degree of ecosystem affections in order to establish better management of activities, especially in areas such as the one under study, which include SCIs and SACs. Furthermore, in the future this analysis will become even more relevant, due to the desire to exploit marine resources such as wind and aquaculture.

7. REFERENCES

Andersen J.H, Al-Hamdani, Z., Harvey, E.T., Kallenbach, E., Murray, C. & Stock, A. (2020). Relative impacts of multiple human stressors in estuaries and coastal waters in the North Sea-Baltic Sea transition zone. *Science of the Total Environment*, 704: 135316.

Andersen, J.H., Stock, A., Mannerla, M., Heinänen, S. & Vinther, M.M. (2013). Human uses, pressures and impacts in the eastern North Sea. Aarhus University, DCE – Danish Centre for Environmental and Energy. *Technical Report from DCE- Danish Centre for Environmental and Energy*, 18: 136 pp.

Ban, N. C., Hussein, M. A. & Jeff, A.A. (2010). Cumulative impact mapping: Advances, relevance and limitations to marine management and conservation, using Canada's Pacific waters as a case study. *Marine Policy*, 34: 876-886.

Ban, N.C. & Alder, J. (2007). How wild is the ocean? Assessing the intensity of anthropogenic marine activities in British Columbia, Canada. *Aquatic Conservation*, 18(1): 55-85.

Barbosa, A., Martín, B., Iglesias-Campos, A., Torres, J.A., Barbière, J., Hermoso, Virgilio, Domisch, S., Langhans, S.D., Martínez-López, J., García-Padilla, M. Gil-Jiménez, Y., Delacámara, G., Teixeira, H., Lillebö, A. & Nogueira, A. (2018). Case Study 2 Report: The Intercontinental Biosphere Reserve of the Mediterranean: Andalusia (Spain) – Morocco. *Aquacross*, D9.2: 53 pp.

Batista, M.I., Henriques, S., País, M.P. & Cabral, H.N. (2014). Assessment of cumulative human pressures on a coastal area: Integrating information for MPA planning and management. *Ocean & Coastal Management* 102: 248-257.

Bellman, M. A., Heppell, S. A., & Goldfinger, C. (2005). Evaluation of a US west coast groundfish habitat conservation regulation via analysis of spatial and temporal patterns of trawl fishing effort. *Canadian Journal of Fisheries and Aquatic Sciences*, 62: 2886–2900.

Bevilacqua, S., Guarnieri, G., Farella, G., Terlizzi, A. & Fraschetti, S. (2018). A regional assessment of cumulative impact mapping on Mediterranean coralligenous outcrops. *Nature. Scientific reports* 8: 1757.

Borgwardt, F., Robinson, L., Trauner, D., Teixeira, H., Nogueira, A.J.A., Lillebø, A.I., Piet, G., Kuemmerlen, M., O'Higgins, T., McDonald, H., Arevalo-Torres, J., Barbosa, A.L., Iglesias-Campos, A., Hein, T. & Culhane, F. (2019). Exploring variability in environmental impact risk from human activities across aquatic ecosystems. *Science of the.Total Environment*, 652: 1396–1408

Centro de Estudios de Puertos y Costas (CEPYC) & Centro de Estudios y Experimentación de Obras Públicas (CEDEX). (2021). Planes de Ordenación del Espacio Marítimo. III. Diagnóstico. Los sectores marítimos: situación actual y previsiones de desarrollo futuro o potencial. A. Demarcación Marina Noratlántica. *Ministerio para la Transición Ecológica y el Reto Demográfico (MITERD)*, 412 pp.

Coordinating Working Party on Fishery Statistics (CWP). (2016). INTERNATIONAL STANDARD STATISTICAL CLASSIFICATION OF FISHING GEAR (ISSCFG). *Coordinating Working Party on Fishery Statistics (CWP) Secretariat.* Food Agriculture Organization of the United Nations (FAO), 2 pp.

Dailianis, T., Smith, C.J., Papadopoulou, N., Gerovasileiou, V., Sevastou, K., Bekkby, T., Bilan, M., Billett, D., Boström, C., Carreiro-Silva, M., Danovaro, R., Fraschetti, S., Gagnon, K., Gambi, C., Grehan, A., Kipson, S., Kotta, J., McOwen, C.J., Morato, T., Ojaveer, H., Pham, C.K. & Scrimgeour, R. (2018). Human activities and resultant pressures on key European marine habitats: An analysis of mapped resources. *Marine Policy*, 98: 1-10.

De la Torriente, A. Aguilar, R., González-Irusta, J.M., Blanco, M & Serrano, A. (2020). Habitat forming species explain taxonomic and functional diversities in a Mediterranean seamount. *Ecological Indicators*, 118: 106747.

De la Torriente, D.A., González-Irusta, J.M., Serrano, A., Aguilar, R. Sánchez, F., Blanco, M. & Punzón, A. (2022). Spatial assessment of benthic habitats vulnerability to bottom fishing in a Mediterranean seamount. *Marine Policy*, 135: 104850.

Depellegrin, D., Menegon, S., Farella, G., Ghezzo, M., Gissi, E., Sarreta, A., Venier, C. & Barbanti, A. (2017). Multi-objective spatial tools to inform maritime spatial planning in the Adriatic Sea. *Science of the Total Environment*, 609: 1627-1639.

Deter, J., Descamp, P., Ballesta, L., Boissery, P. & Holon, F. (2012). A preliminary study toward an index based on coralligenous assemblages for the ecological status assessment of Mediterranean French coastal waters. *Ecological Indicators*, 20: 345-352.

Eastwood, P.D., Mills, C.M., Aldridge, J.N., Houghton, C.A. & Rogers, S.I. (2007). Human activities in UK offshore waters: an assessment of direct, physical pressure on the seabed. *ICES Journal of Marine Science*, 64: 453-463.

Eigaard, O.R., Bastardie, F., Hintzen, N.T., Buhl-Mortensen, L., Buhl-Mortensen, P., Catarino, R., Dinesen, G.E., Egekvist, J., Fock, H.O., Geitner, K., Gerritsen, H.D., Marín-González, M., Jonsson, P., Kavadas, S., Laffargue, P., Lundy, M., Gonzalez-Mirelis, G., Nielsen, J.R., Papadopoulou, N., Posen, P.E., Pulcinella, J., Russo, T., Sala, A., Silva, C., Smith, C., Vanelslander, B. & Rijnsporp, A.D. (2017). The footprint of bottom trawling in European waters: distribution, intensity, and seabed integrity. *ICES Journal of Marine Science*, 74(3): 847-865.

Elliott, M., Borja, A. & Cormier, R. (2020). Activity-footprints and effects-footprints – Walking the pathway to determining and managing human impacts in the sea. *Marine Pollution Bulletin*, 155: 111201.

Elliott, M., Borja, A. & Cormier, R. (2020). Activity-footprints, pressures-footprints and effect-footprints – Walking the pathway to determining and mapping human impacts in the sea. *Marine Pollution Bulletin*, 155: 111201.

Elliott, M., Boyes, S.J., Barnard, S. & Borja, A. (2018). Using best expert judgement to harmonise marine environmental status assessment and maritime spatial planning. *Marine Pollution Bulleting*, 133: 367-377.

European Commission (EC). (2008). Directiva 2008/56/CE del Parlamento Europeo y del Consejo de 17 de junio de 2008 por la que se establece un marco de acción comunitaria para la política del medio marino (Directiva Marco sobre la Estrategia Marina). *Diario Oficial de la Unión Europea*, L 164: 19-40.

European Commission (EC). (2017a). Decisión (UE) 2017/845 de la Comisión de 17 de mayo de 2017 por la que se modifica la Directiva 2008/56/CE del Parlamento Europeo y del Consejo en lo que se refiere a las listas indicativas de elementos que deben tomarse en consideración a la hora de elaborar estrategias marinas. *Diario Oficial de la Unión Europea*, L125: 27-33

European Commission. (2017b). Decisión (UE) 2017/848 de la Comisión de 17 de mayo de 2017 por la que se establecen los criterios y las normas metodológicas aplicables al buen estado medioambiental de las aguas marinas, así como especificaciones y métodos normalizados de seguimiento y evaluación, y por la que se deroga la Decisión 2010/477/UE. *Diario Oficial de la Unión Europea*, L 125: 27-33.

European Marine Observation and Data Network (EMODnet). (11 Nov 2021). Official Release of EUSeaMap 2021. Retrieved on 05 July, 2022, from: https://www.emodnet-seabedhabitats.eu/news/official-release-of-euseamap-2021/

Evans, D., Aish, A., Boon, A., Condé, S., Connor, D., Gelabert, E. Michez, N., Parry, M., Richard, D., Salvati, E. & Tunesi, L. (2016). Revising the marine section of the EUNIS Habitat classification. *European Topic Centre on Biological Diversity*, A/2016: 8pp.

Fernandes, M.L., Esteves, T.C., Oliveira, E.R. & Alves, F.L. (2017). How does the cumulative impacts approach support maritime spatial planning? *Ecological Indicators*, 73: 189-202.

Fernandes, M.L., Quintela, A. & Alves, F.L. (2018). Identifying conservation priority areas to inform maritime spatial planning: A new approach. *Science of the Total Environment*, 639: 1088-1098.

Fernandes, M.L., Quintela, A., Cervera-Núñez, C., Campillos-Llanos, M., Sousa, L.P., Casimiro, D., Matías, J.O., Simão, A.P., Gómez-Ballesteros, M. & Alves, F.L. (2021). D2.3 Transboundary Impact Assessment in the north-western Iberian Peninsula. *SIMAtlantic project*, 27pp.

Fernandes, M.L., Sousa, L.P., Quintela, A., Marques, M., Reis, J., Simão A.P., Castro, A.T., Marques J.M. & Alves F.L. (2020). Mapping the future: Pressures and impacts in the Portuguese maritime spatial planning. *Science of the Total Environment* 715: 136863.

Ferrà, C., Tassetti, A.N., Grati, F., Pellini, G., Polidori, P., Scarcella, G. & Fabi, G. (2017). Mapping change in bottom trawling activities in the Mediterranean Sea through AIS data. *Marine Policy* 94: 275-281.

Fisheries Research and Development Corporation (FRDC). (S.f.). Hook and line. Retrieved on September 02, 2022, from: https://fish.gov.au/fishing-methods/hook-and-line.

Foden, J., Rogers, S.I. & Jones A.P. (2011). Human pressures on UK seabed habitats: a cumulative impact assessment. *Marine Ecology Progress Series*, 428: 33-47.

Foden, J., Rogers, S.I. & Jones, A.P. (2010). Recovery of UK seabed habitats from benthic fishing an aggregate extraction – towards a cumulative impact assessment. *Marine Ecology*. *Progress Series* 411: 259-270.

Foley, M.M., Halpern, B.S., Micheli, F., Armsbya, M.H., Caldwell, M.R., Crain, C.M., Prahler, E., Rohr, N., Sivas, D., Beck, M.W., Carr, M.H., Crowder, L.B., Duffy, J.E., Hacker, S.D., McLeod, K.L., Palumbi, S.R., Petersonk, C.H., Regan, H.M., Ruckelshaus, M.H., Sandifer, P.A. & Steneck, R.S. (2010). Guiding ecological principles for marine spatial planning. *Marine Policy* 34(5): 955-966.

Frazão-Santos, C., Agardy, T., Andrade, F., Crowder, L.B., Ehler, C.N. & Orbach, M.K. (2021). Major challenges in developing marine spatial planning. *Marine Policy* 132: 103248.

García-Alegre, A., Sánchez, F., Gómez-Ballesteros, M., Hinz, H., Serrano, A. & Parra, S. (2014). Modelling and mapping the local distribution of representative species on the Le Danois Bank, El Cachucho Marine Protected Area (Cantabrian Sea). *Deep Sea Research II*, 106: 151-164.

Giakoumi, S., Sini, M., Gerovasileiou, V. Mazor, T., Beher, J. Possingham, H.P., Abdulla, A., Çinar, M.E., Dendrinos, P., Gucu, A.C., Karamanlidis, A.A., Rodic, P., Panayotidis, P., Taskin, E., Jaklin, A., Voultsiadou, E., Webster, C., Zenetos, A. & Katsanevakis, S. (2013). Ecoregion-Based Conservation Planning in the Mediterranean: Dealing with Large-Scale Heterogeneity. *PLoS ONE*, 8(10): e76449.

Giménez-Casalduero, F., Gomáriz-Castillo, F., Canales, R. & Calvín J.C. (2018). Identifying the Conservation State of Marine Rocky Habitats along the Western Mediterranean Using Focal Species. *Journal of Coastal Research*, 34(5): 1176-1187.

Gobert, S., Sartoretto, S., Rico-Raimondino, V., Andral, B., Chery, A., Lejeune, P. & Boissery, P. (2009). Assessment of the ecological status of Mediterranean French coastal waters as requires by the Water Framework Directive using the *Posidonia oceanica* Rapid Easy Index: PREI. *Marine Pollution Bulletin*, 58: 1727-1733.

González-Irusta, J.M., De la Torriente, A., Punzón, A., Blanco, M. & Serrano, A. (2018). Determining and mapping species sensitivity to trawling impacts: the Benthos Sensitivity Index to Trawling Operations (BESITO). *ICES Journal of Marine Science*, 75(5): 1710-1721.

Grieve, C., Brady, D.C. & Polet, H. (2014). Review of habitat dependent impacts of mobile and static fishing gears that interact with the seabed. *Marine Stewardship Council Science Series*, 2: 18-88.

Halpern, B.S. & Fujita, R. (2013). Assumptions, challenges, and future directions in cumulative impact analysis. *Ecosphere*, 4(10): 1-11.

Halpern, B.S., Frazier, M., Potapenko, J., Casey, K.S., Koenig, K., Longo, C., Stewart-Lowndes, J., Cotton-Rockwood, R., Seling, E.R., Seloke, K.A. & Walbridge, S. (2015). Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nature Communications* 6: 7615.

Halpern, B.S., Kappel, C.V., Selkoe, K.A., Micheli, F., Ebert, C.M., Kontgis, C., Crain, C.M., Martone, R.G., Shearer, C. & Teck, S.J. (2009). Mapping cumulative human impacts to California Current marine ecosystems. *Conservation Letters*, 2: 138-148.

Halpern, B.S., Walbridge S, Selkoe KA, Kappel C V., Micheli F, D'Agrosa C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D. Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R. & Watson, R. (2008). A Global Map of Human Impact on Marine Ecosystems. Science 319 (5865): 948-952.

Hammar, L., Molander, S., Palsson, J., S. Crona, J., Carneiro, G, Johansson, T., Hume, D., Kagesten, G., Mattsson, D., Törnqvist, O., Zillén, L., Mattsson, M., Bergström, U., Perry, D., Caldow, C. & Andersen, J.H. (2020). *Science of the Total Environment* 734: 139024.

Helsinki Commission (HELCOM) (2010a) Ecosystem Health of the Baltic Sea 2003–2007: HELCOM Initial Holistic Assessment. *Baltic Sea Environment Proceedings*, 122: 63pp.

Helsinki Commission (HELCOM) (2010b). Towards a tool for quantifying the anthropogenic pressures and potential impacts in the Baltic Sea marine environment. A background document on the method, data preparation and testing of the Baltic Sea Pressure and Impact Indices. *Baltic Sea Environment Proceedings* 125: 69 pp.

Hintzen, N.T., Aarts, G., Poos, J.J., Van der Reijden, K.J. & Rijnsdorp, A.D. (2021). Quantifying habitat preference of bottom trawling gear. *ICES Journal of Marine Science*, 78(1): 172-184.

Holon F, Mouquet N, Boissery P, Bouchoucha M, Delaruelle G, Tribot A-S & Deter, J. (2015). Fine-Scale Cartography of Human Impacts along French Mediterranean Coasts: A Relevant Map for the Management of Marine Ecosystems. *PLoS ONE* 10(8): e0135473.

International Council for the Exploration of the Sea (ICES) (2019b). Workshop to evaluate and test operational assessment of human activities causing physical disturbance and loss to seabed habitats (MSFD D6 C1, C2 and C4) (WKBEDPRES2). *ICES Scientific Reports*, 1(69): 87pp.

International Council for the Exploration of the Sea (ICES). (2016). Report of the Workshop on guidance in how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats (WKFBI). *ICES Scientific Reports*, 46: 109 pp.

International Council for the Exploration of the Sea (ICES). (2018). Workshop on Scoping for Benthic Pressure Layers D6C2 – From Methods to Operational Data Products (WKBEDPRESS1). *ICES Scientific Reports*, 1(15): 37pp

International Council for the Exploration of the Sea (ICES). (2019a). Workshop on Scoping of Physical Pressure Layers Causing Loss of Benthic Habitats D6C1 – Methods to Operational Data Products (WKBEDLOSS). *ICES Scientific Reports*. 1(15): 49pp

Judd, A., Backhaus, T. & Goodsir, F. (2015). An effective set of principles for practical implementation of marine cumulative effects assessment. *Environmental Science Policy*, 54: 254-262.

Kannen, A. (2014). Challenges for marine spatial planning in the context of multiple sea uses, policy arenas and actors based on experiences from the German North Sea. *Regional Environment Chang*e, 14: 2139-2150.

Katsanevakis, S., Stelzenmüller, V., South, A., Sørensen, T.K., Jones, P.J.S., Kerr, S., Badalamenti, F., Anagnostou, C., Breen, P., Chust, G., D'Anna, G., Duijn, M., Filatova, T., Fiorentino, F., Hulsman, H., Johnson, K., Karageorgis, A.P., Kröncke, I., Mirto, S., Pipitone, C., Portelli, S., Qiu, W., Reiss, H., Sakellariou, D., Salomidi, M., van Hoof, L., Vassilopoulou, V., Vega Fernández, T., Vöge, S., Weber, A., Zenetos, A. & Hofstede, R.T. (2011). Ecosystem-based marine spatial management: review of concepts, policies, tools, and critical issues. *Ocean Coastal Manag*ement, 54: 807-820.

Kellon, D. & Arvai, J. (2011). Five propositions for improving decision making about the environment in developing communities: insights from the decision sciences. *Journal of Environmental Management*, 92: 363-371.

Kenny, A.J., Jenkins, C., Wood, D., Bolam, S.G., Mitchell, P., Scougal, C. & Judd, A. (2018). Assessing cumulative human activities, pressures, and impacts on North Sea benthic habitats using a biological traits approach. *ICES Journal of Marine Science*, 75(3): 1080-1092.

Knights, A.M., Koss, R.S. & Robinson, L.A. (2013). Identifying common pressure pathways from a complex network of human activities to support ecosystem-based management. *Ecological Applications*, 23: 755-765.

Korpinen S., Meidinger M. & Laamanen M. (2013). Cumulative impacts on seabed habitats: An indicator for assessments of good environmental status. *Marine Pollution Bulleting*, 74: 311-319.

Larcombe, J. W. P., McLoughlin, K. J., & Tilzey, R. D. J. (2001). Trawl operations in the South East Fishery, Australia: spatial distribution and intensity. *Marine and Freshwater Research*, 52: 419–430.

Link, J.S., Brodziak, J.K.T., Edwards, S.F., Overholtz, W.J., Mountain, D., Jossi, J.W. & Fogarty, M.J. (2002). Marine ecosystem assessment in a fisheries management context. *Canadian Journal of Fisheries and Aquatic Sciences*, 59: 1429-1440.

Micheli, F., Halpern, B.S., Walbridge, S., Ciriaco, S., Ferretti, F., Fraschetti, S., Lewison, R., Nykjaer, L. & Rosenberg, A.A. (2013). Cumulative Human Impacts on Mediterranean and Black Sea Marine Ecosystems: Assessing Current Pressures and Opportunities. *PLoS ONE*, 8(12): e79889.

Ministerio para la Transición Ecológica y el Reto Demográfico (MITERD). (2019a). Parte II: Análisis de Presiones e Impactos. *Estrategias Marinas de España (EsMarEs) de la Demarcación noratlántica*, 20 pp.

Ministerio para la Transición Ecológica y el Reto Demográfico (MITERD). (2019b). Anexo Parte III: Fichas del Análisis Socioeconómico. *Estrategias Marinas de España (EsMarEs) de la Demarcación noratlántica*, 187 pp

Ministerio para la Transición Ecológica y el Reto Demográfico (MITERD). (03 de agosto de 2022). Estrategias Marinas. Madrid, España. *Estrategias Marinas de España (EsMarEs)*. Retrieved on August 14, 2022, from: https://www.MITERD.gob.es/es/costas/temas/proteccion-medio-marino/estrategias-marinas/

Möckel, S. (2017). The European ecological network "Natura 2000" and the appropriate assessment for projects and plans under Article 6(3) of the Habitats Directive. *Nature Conservation*, 23: 1-29.

Neslo, R., Micheli, F., Kappel, C.V., Selkoe, K.A., Halpern, B.S. & Cooke, R.M. (2008). Modeling Stakeholder Preferences with Probabilistic Inversion: Application to Prioritizing Marine ecosystem. In Real-time and deliberative decision making. Vulnerabilities. *Edited by Linkov, I., Ferguson E. & Magar, V.S. (Springer)*: 265-285. Amsterdam, The Netherlands.

Office of Protected Resources. (February 22, 2021). Fishing Gear: Gillnets. *NOAA FISHERIES*. Retrieved on September 02, 2022, from: https://www.fisheries.noaa.gov/national/bycatch/fishing-gear-gillnets.

Oosterbaan, L., Judd, A., Nixon, E., Lauwaert, B., Enserink, L., Karman, C., Svoboda, A., Vink, R., Degre, E., Langaas, A., Thomsen, F., Moffat, C., Ware, K., Connor, D., Vivian, C., Birchenough, A., Stelzenmuller, V., Kroeger, S., Wasserthal, R., Merck, T., Wenzel, C., Buceta, J., Marin-Cabezas, P., Snoeren, B., Mouat, J. & Thompson, S. (2009). Trend analysis of maritime human activities and their collective impact on the OSPAR maritime area. *OSPAR Commission - Biodiversity Series*, 443: 50 pp.

Piet, G.J., Tamis, J.E., Volwater, J., de Vries, P., van der Wal, J.T. & Jongbloed, R.H. (2021). A roadmap towards quantitative impact assessments: Every step of the way. *Science of Total Environment*, 784: 146847.

Pipitone, C., Badalamenti, F., D'Anna, G. & Patti, B. (2000). Fish biomass increase after a four-year trawl ban in the Gulf of Castellammare (NW Sicily, Mediterranean Sea). *Fisheries Research*, 48: 23-30.

Punzón, A., Arronte, J.C., Sánchez, F. & García-Alegre, A. (2016). Spatial characterization of the fisheries in the Avilés Canyon System (Cantabrian Sea, Spain). *Ciencias Marinas*, 42(4): 237-260.

Raicevich, S., Korpinen, S., Schoeder, A., Muller, H., Lancker, V.V., Vaz, S., Punzón, A., Sandman, A., Wijnhoven, S., Häubner, N., Connor, D., Jochen, K., Papadopoulou, N., Canals, M. and others (Thecnical Group on seabed habitats and sea floor integrity - TGSeabed). (2022). Guidance to the assessment of the sea-floor integrity under the EU Marine Strategy Framework Directive v2-1. *Communication and Information Resource Center for Administrations, Businesses and Citizens (CIRCABC)*, 132 pp.

Ravasio, P. (February 8, 2022). The True Cost: Tax Money x Sustainable Development: The Fishing Industry. *SHIRAHIME*. Retrieved on September 02, 2022, from: https://shirahime.ch/2022/02/the-true-cost-tax-money-x-sustainable-development-the-fishing-industry/

Rees, T. (2003). "C-Squares", a New Spatial Indexing System and its Applicability to the Description of Oceanographic Datasets. *Oceanography* 16 (1): 11-19.

Ríos, P. Altuna, A., Frutos, I., Manjón-Cabeza, E., García-Guillén, L., Macías-Ramírez, A., Ibarrola, T.P., Gofas, S., Taboada, S., Souto, J., Álvarez, F., Saiz-Salinas, J.I., Cárdenas, P., Rodríguez-Cabello, C., Lourido, A., Boza, C., Rodríguez-Basalo, A., Prado, E., Abad-Uribarren, A., Parra, S., Sánchez, F. &

Cristobo, J. (2022). Avilés Canyon System: Increasing the benthic biodiversity knowledge. *Estuarine, Coastal and Shelf Science*, 274: 107924.

Rodríguez-Basalo, A., Prado, E., Sánchez, F., Ríos, P., Gómez-Ballesteros, M. & Cristobo, J. (2021). High Resolution Spatial Distribution for the Hexactinellid Sponges *Asconema setubalense* and *Pheronema carpenteri* in the Central Cantabrian Sea. *Frontiers in Marine Science*, 8(612761): 15pp.

Sánchez, F., Gómez-Ballesteros, M., González-Pola, C. & Punzón, A. (2014). Sistema de cañones submarinos de Avilés. Proyecto LIFE +INDEMARES. *Editorial Fundación Biodiversidad del Ministerio de Agricultura, Alimentación y Medio Ambiente*, 112 pp.

Selkoe, K.A., Halpern, B.S., Ebert, C.M., Franklin, E.C., Selig, E.R., Casey, K.S., Bruno, J. & Toonen, R.J. (2009). A map of human impacts to a "pristine" coral reef ecosystem, the Papahānaumokuākea Marine National Monument. *Coral Reefs* 28(3): 635-650.

Serrano, A., De la Torriente, A., Punzón, A., Blanco, M. Bellas, J., Durán-Muñoz, P., Murillo, F.J., Sacau, M., García-Alegre, A., Antolínez, A., Elliott, S., Guerin, L., Vina-Herbón, C., Marra, S. & González-Irusta, J.M. (2022). Sentinels of Seabed (SoS) indicator: Assessing benthic habitats condition using typical and sensitive species. *Ecological Indicators*, 140: 108979.

Serrano, A., Rodríguez-Cabello, C., Sánchez, F., Velasco, F., Olaso, I. & Punzón, A. (2011). Effects of anti-trawling artificial reefs on ecological indicators of inner shelf fish and invertebrate communities in the Cantabrian Sea (southern Bay of Biscay). *Journal of the Marine Biological Association of the United Kingdom*, 91(3): 623-633.

Stelzenmüller, V. Rogers, S.I. & Mills, C.M. (2008). Spatio-temporal patterns of fishing pressure on UK marine landscapes, and their implications for spatial planning and management. *ICES Journal of Marine Science*, 65(6): 1081-1091.

Stelzenmüller, V., Lee, J., South, a & Rogers, S.I. (2010). Quantifying cumulative impacts of human pressures on the marine environment: a geospatial modelling framework. *Marine Ecology Progress Series*, 398: 19-32.

Teck, S.J., Halpern, B.S., Kappel, C.V., Micheli, F., Selkoe, K.A., Crain, C.M., Martone, R., Shearer, C., Arvai, J., Fischhoff, B., Murray, G., Neslo, R. & Cooke, R. (2010). Using expert judgment to estimate marine ecosystem vulnerability in the California Current. *Ecological Applications*, 20(5): 1402-1416.

Templado, J., Capa, M., Guallart, J. & Luque, A. (2009). 1170 Arrecifes. *Bases ecológicas preliminares para la conservación de los tipos de hábitat de interés comunitario en España*. Madrid: Ministerio de Medio Ambiente, y Medio Rural y Marino, 142 pp.

Vasquez, M., Allen, H., Manca, E., Castle, L., Lillis, H., Agnesi, S., Al Hamdani, Z., Annunziatellis, A., Askew, N., Bekkby, T., Bentes, L., Doncheva, V., Drakopoulou, V., Duncan, G., Gonçalves, J., Inghilesi, R., Laamanen, L., Loukaidi, V., Martin, S., McGrath, F., Mo, G., Monteiro, P., Muresan, M. Nikolova, C., O'Keeffe, E., Pesch, R., Populus, J., Punder, J., Ridgeway, A., Sakellariou, D., Teaca, A., Tempera, F., Todorova, V., Tunesi, L. & Virtanen, E. (2021). EUSeaMap 2021, A European broad-scale seabed habitat map. Thechnical Report. *EMODnet Thematic Lot n° 2 – Seabed Habitats*: 25 pp.

Victorero, L., Robert, K., Robinson, L.F., Taylor, M.L. & Huvenne, V.A.I. (2018). Species replacement dominates megabenthos beta diversity in a remote seamount setting. *Scientific Reports* 8: 4152.

Willsteed, E., Gill, A.B., Birchenough, S.N.R. & Jude, S. (2017). Assessing the cumulative environmental effects of marine renewable energy developments: establishing common ground. *Science of the Total Environment*, 577: 19-32.

WEBSITE RESOURCES

1. EMODnet, 2021: https://www.emodnet-seabedhabitats.eu/news/official-release-of-euseamap-2021/
2. FRDC, s.f.: https://fish.gov.au/fishing-methods/hook-and-line
3. MITERD, 2022: https://www.MITERD.gob.es/es/costas/temas/proteccion-medio-marino/estrategias-marinas/
4. Office of Protected Resources, 2021: https://www.fisheries.noaa.gov/national/bycatch/fishing-gear-gillnets.
5. Ravasio, 2022: https://shirahime.ch/2022/02/the-true-cost-tax-money-x-sustainable-development-the-fishing-industry/

SUPPLEMENTARY MATERIAL

MATERIAL AND METHODS

I. Relevant scripts used

Modified Csquare script from VMSTOOLS (Rees, T., 2003).

```
csquare.mod <- function(lon, lat, degrees){
  if (length(lon) != length(lat))
    stop("length of longitude not equal to length of latitude")
  if (!degrees %in% c(10, 5, 1, 0.5, 0.1, 0.05, 0.01,0.005,0.001))
    stop("degrees specified not in range: c(10,5,1,0.5,0.1,0.05,0.01,0.005,0.001)")
  dims <- length(lon)
  quadrants <- array(NA, dim = c(5, 6, dims), dimnames = list(c("globalQuadrant","intmQuadrant1", "intmQuadrant2", "intmQuadrant3","intmQuadrant4"),c("quadrantDigit", "latDigit", "lonDigit","latRemain", "lonRemain", "code"),seq(1, dims, 1)))
  quadrants["globalQuadrant", "quadrantDigit",] <- 4 - (((2 * floor(1 + (lon/200))) - 1) * ((2 * floor(1 + (lat/200))) + 1))
  quadrants["globalQuadrant", "latDigit", ] <- floor(abs(lat)/10)
  quadrants["globalQuadrant", "lonDigit", ] <- floor(abs(lon)/10)
  quadrants["globalQuadrant", "latRemain", ] <- round(abs(lat) - (quadrants["globalQuadrant", "latDigit", ] * 10), 7)
  quadrants["globalQuadrant", "lonRemain", ] <- round(abs(lon) - (quadrants["globalQuadrant", "lonDigit", ] * 10), 7)
  quadrants["globalQuadrant", "code", ] <- quadrants["globalQuadrant", "quadrantDigit", ] * 1000 + quadrants["globalQuadrant", "latDigit", ] * 100 + quadrants["globalQuadrant", "lonDigit", ]
  quadrants["intmQuadrant1", "quadrantDigit", ] <- (2 * floor(quadrants["globalQuadrant", "latRemain", ] * 0.2)) + floor(quadrants["globalQuadrant", "lonRemain", ] * 0.2) + 1
  quadrants["intmQuadrant1", "latDigit", ] <- floor(quadrants["globalQuadrant", "latRemain", ])
  quadrants["intmQuadrant1", "lonDigit", ] <- floor(quadrants["globalQuadrant", "lonRemain", ])
  quadrants["intmQuadrant1", "latRemain", ] <- round((quadrants["globalQuadrant","latRemain", ] - quadrants["intmQuadrant1", "latDigit", ]) * 10, 7)
  quadrants["intmQuadrant1", "lonRemain", ] <- round((quadrants["globalQuadrant", "lonRemain", ] - quadrants["intmQuadrant1", "lonDigit", ]) * 10, 7)
  quadrants["intmQuadrant1", "code", ] <- quadrants["intmQuadrant1", "quadrantDigit", ] * 100 + quadrants["intmQuadrant1", "latDigit", ] * 10 + quadrants["intmQuadrant1", "lonDigit", ]
  quadrants["intmQuadrant2", "quadrantDigit", ] <- (2 * floor(quadrants["intmQuadrant1", "latRemain", ] * 0.2)) + floor(quadrants["intmQuadrant1", "lonRemain", ] * 0.2) + 1
  quadrants["intmQuadrant2", "latDigit", ] <- floor(quadrants["intmQuadrant1", "latRemain", ])
  quadrants["intmQuadrant2", "lonDigit", ] <- floor(quadrants["intmQuadrant1", "lonRemain", ])
  quadrants["intmQuadrant2", "latRemain", ] <- round((quadrants["intmQuadrant1", "latRemain", ] - quadrants["intmQuadrant2", "latDigit", ]) * 10, 7)
  quadrants["intmQuadrant2", "lonRemain", ] <- round((quadrants["intmQuadrant1", "lonRemain", ] - quadrants["intmQuadrant2", "lonDigit", ]) * 10, 7)
  quadrants["intmQuadrant2", "code", ] <- quadrants["intmQuadrant2", "quadrantDigit", ] * 100 + quadrants["intmQuadrant2", "latDigit", ] * 10 + quadrants["intmQuadrant2", "lonDigit", ]
  quadrants["intmQuadrant3", "quadrantDigit", ] <- (2 * floor(quadrants["intmQuadrant2", "latRemain", ] * 0.2)) + floor(quadrants["intmQuadrant2", "lonRemain", ] * 0.2) + 1
  quadrants["intmQuadrant3", "latDigit", ] <- floor(quadrants["intmQuadrant2", "latRemain", ])
  quadrants["intmQuadrant3", "lonDigit", ] <- floor(quadrants["intmQuadrant2", "lonRemain", ])
  quadrants["intmQuadrant3", "latRemain", ] <- round((quadrants["intmQuadrant2","latRemain", ] - quadrants["intmQuadrant3", "latDigit", ]) * 10, 7)
  quadrants["intmQuadrant3", "lonRemain", ] <- round((quadrants["intmQuadrant2", "lonRemain", ] - quadrants["intmQuadrant3", "lonDigit", ]) * 10, 7)
  quadrants["intmQuadrant3", "code", ] <- quadrants["intmQuadrant3", "quadrantDigit", ] * 100 + quadrants["intmQuadrant3", "latDigit", ] * 10 + quadrants["intmQuadrant3", "lonDigit", ]
```

```
  quadrants["intmQuadrant4", "quadrantDigit", ] <- (2 * floor(quadrants["intmQuadrant3", "latRemain", ] * 0.2))
+ floor(quadrants["intmQuadrant3", "lonRemain", ] * 0.2) + 1
  quadrants["intmQuadrant4", "latDigit", ] <- floor(quadrants["intmQuadrant3", "latRemain", ])
  quadrants["intmQuadrant4", "lonDigit", ] <- floor(quadrants["intmQuadrant3", "lonRemain", ])
  quadrants["intmQuadrant4", "latRemain", ] <- round((quadrants["intmQuadrant3","latRemain", ] -
quadrants["intmQuadrant4", "latDigit", ]) * 10, 7)
  quadrants["intmQuadrant4", "lonRemain", ] <- round((quadrants["intmQuadrant3", "lonRemain", ] -
quadrants["intmQuadrant4", "lonDigit", ]) * 10, 7)
  quadrants["intmQuadrant4", "code", ] <- quadrants["intmQuadrant4","quadrantDigit", ] * 100 +
quadrants["intmQuadrant4","latDigit", ] * 10 + quadrants["intmQuadrant4", "lonDigit", ]
  if (degrees == 10)
    CSquareCodes <- quadrants["globalQuadrant", "code",]
  if (degrees == 5)
    CSquareCodes <- paste(quadrants["globalQuadrant", "code", ], ":", quadrants["intmQuadrant1",
"quadrantDigit", ], sep = "")
  if (degrees == 1)
    CSquareCodes <- paste(quadrants["globalQuadrant", "code", ], ":", quadrants["intmQuadrant1", "code", ], sep
= "")
  if (degrees == 0.5)
    CSquareCodes <- paste(quadrants["globalQuadrant", "code", ], ":", quadrants["intmQuadrant1", "code", ], ":",
quadrants["intmQuadrant2", "quadrantDigit", ], sep = "")
  if (degrees == 0.1)
    CSquareCodes <- paste(quadrants["globalQuadrant", "code", ], ":", quadrants["intmQuadrant1", "code", ], ":",
quadrants["intmQuadrant2", "code", ], sep = "")
  if (degrees == 0.05)
    CSquareCodes <- paste(quadrants["globalQuadrant", "code", ], ":", quadrants["intmQuadrant1", "code", ], ":",
quadrants["intmQuadrant2", "code", ], ":", quadrants["intmQuadrant3", "quadrantDigit", ], sep = "")
  if (degrees == 0.01)
    CSquareCodes <- paste(quadrants["globalQuadrant", "code", ], ":", quadrants["intmQuadrant1", "code", ], ":",
quadrants["intmQuadrant2", "code", ], ":", quadrants["intmQuadrant3", "code", ], sep = "")
  if (degrees == 0.005)
    CSquareCodes <- paste(quadrants["globalQuadrant", "code", ], ":", quadrants["intmQuadrant1", "code", ], ":",
quadrants["intmQuadrant2", "code", ], ":", quadrants["intmQuadrant3", "code", ], ":",
quadrants["intmQuadrant4", "quadrantDigit", ], sep = "")
  if (degrees == 0.001)
    CSquareCodes <- paste(quadrants["globalQuadrant", "code", ], ":", quadrants["intmQuadrant1", "code", ], ":",
quadrants["intmQuadrant2", "code", ], ":", quadrants["intmQuadrant3", "code", ], ":",
quadrants["intmQuadrant4", "code", ], sep = "")

  return(CSquareCodes)
}
```

Join data to csquare (once modified Csquare has been applied)

```
resolution <- 0.01

dat$csq<-csquare.mod(dat$long,dat$lat,resolution)

puntos<-aggregate(ID_new~csq,data=dat,FUN=sum)

gr_dat<-merge(gr,puntos,all.x=T)
```

Join habitat to data with csquare

```
puntos<-as.data.frame(gr_ef)[,c("csq","LONG_CENT","LAT_CENT")]

puntos_sf <- st_as_sf(puntos, coords = c("LONG_CENT", "LAT_CENT"), crs = 4326, agr = "constant",
stringsAsFactors = FALSE,remove = TRUE)

ID<-over(as(puntos_sf, "Spatial"), as(hab[,c("MSFD_BH17","geometry")], "Spatial"))

hab_c<-as.character(ID$MSFD_BH17)
```

```
str(hab_c)
table (hab_c)
hab_c[-which(is.na(hab_c))]
gr_ef$hab<-hab_c
table (gr_ef$hab)
head(gr_ef[-which(is.na(gr_ef$hab)),])
```

Join all data and creation of dynamic table

```
all_data<-merge (data1, data2, all.x=T)
tab<-tapply(all_data$presencia, list(all_data$csq), sum) #create dynamic table
all_data.hab<-aggregate(presencia~csq+hab,data=all_data,FUN=sum)
```

Nested General Linear Model

```
MtotalH <- dbhora2 %>%
  group_by (Csquare, gear) %>%
  glm (hour ~ year + gear, data = .)
```

REFERENCES

Rees, T. (2003). “C-Squares”, a New Spatial Indexing System and its Applicability to the Description of Oceanographic Datasets. Oceanography 16 (1): 11-19.