



OSPAR- Biodiversity Indicators

## Coordinated Environmental Monitoring Programme (CEMP) Guidelines

Common Indicator <sup>1</sup>Sentinels of the Seabed (SoS)

Agreement 2023-02<sup>2</sup>

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<sup>1</sup> Sentinel of the Seabed (SoS) indicator is the updated version of the common indicator BH1 Typical species composition

<sup>2</sup> English only

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# CEMP Guidelines Common indicator Sentinels of the Seabed (SoS)

## 1. Introduction

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This document describes the methodology for the "Sentinels of the Seabed"(SoS) indicator, developed within the OSPAR common indicator group of Benthic Habitats (BH), which is also called "Typical species composition"(BH1); an indicator lead by Spain, common in region IV and candidate in other regions. This document is an OSPAR Guideline for the Coordinated Environmental Monitoring and Assessment Programme (CEMP) specific and exclusive of the SoS indicator.

### 1.1. General introduction to the indicator

The aim of this indicator is to assess the environmental status of an habitat using the proportional abundance (in biomass or number) of the sentinel species characteristics of this habitat in reference conditions across a pressure gradient. The "sentinel species" of an habitat are determined based on two requirements:

1. The species must be frequently found in the pristine habitat.
2. The species must be sensitive to the studied pressure, or if this is not possible, at least not favoured by the pressure (opportunistic response).

The SoS indicator was developed as BH1 (Typical species composition) during the EcApRHA project (Applying an Ecosystem Approach to (sub) Regional Habitat Assessment) in the frame of OSPAR and the Marine Strategy Framework Directive(MSFD) for the descriptor 6, sea floor integrity, following the first commission decisions on criteria and methodological standards on GES (2010/77/EU). Now the approach is being updated as the Sentinels of the Seabed (SoS) indicator to fulfil better the requirements of the second commission decision on GES (2017/848/EU) in the frame of the NEA-PANACEA project.

A benthic indicator is unlikely to be universally applicable since organisms are not equally sensitive to all types of anthropogenic disturbance (Buhl-Mortensen et al., 2009), to geographical specifications (Dauvin, 2007) and habitat typologies (Tagliapietra et al., 2009). An ideal indicator should be responsive to any stressor type, have low natural variability, provide a response that can be distinguished from natural variation, and be interpretable (Hering et al., 2006). Therefore, SoS shall be capable of detecting changes in the community composition of marine habitats produced by any physical and/or chemical disturbance. In order to fulfil this aim, the SoS indicator adapts to each habitat by selecting a set of typical species (species which are frequent and/or abundant in reference conditions) characteristic of that habitat and specific to it, based on monitoring data. Then, this list of typical species is filtered using sensitivity indexes (e.g. BESITO index, González-Irusta et al. 2018) to select only species which are sensitive to the pressure or, if this is not possible, at least species which did not exhibit opportunistic responses. Since SoS uses other previous indexes to build on them, it is capable of analysing any type of pressure as long as there is an index available to evaluate species sensitivity to that pressure. As expected, the SoS indicator is sensitive to data quality, which will dictate the power and utility of the resultant information. Once the final set of

sentinel species has been selected, changes in the proportion of these species across a pressure gradient can be computed, allowing to generate pressure-state curves (see Elliott et al. 2018). These curves can then be used for two main purposes:

1. To directly evaluate the status of an habitat by transforming pressure units (e.g. swept area ratio) into the proportion of sentinel species (using correlative models, e.g. GAMs), allowing to evaluate the status of the habitat across its extent (Annex I).
2. To provide sensitivity values to the habitats, based on pressure-state curves built across a pressure gradient and then, independent of the level of pressure existent in each specific location (Annex II). These values can then be used for other benthic indicators such as BH3 (see Annex V) or to evaluate the status of the habitat in the sampled stations, providing key information to establish quality thresholds based on ecological information of the habitat. These values can also be used to help in the delimitation of threshold values for pressure layers, for instance, providing valuable information on how much pressure can support a habitat before losing its functionality (see Annex V).

The methodology used has been thoroughly tested and reviewed by national and OSPAR experts through focus workshops. It represents a realistic approach to assess the distribution of impacts across the regions based on current knowledge and using all available evidence. Several scenarios were considered to test its applicability in different marine habitats under different pressures, keeping in mind the features that an ideal indicator should have (Hering et al., 2006). In this CEMP document, the indicator has been tested in different MSFD broad habitats, using endobenthos and epibenthos communities and with two different pressures (pollution and trawling disturbance) to show the full potential of the indicator and its high plasticity. Further testing in other biogeographic regions has already been carried out and is presented in Serrano et al. (2022).

## 2. Indicator specifications

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### 2.1. Components

*Biodiversity component:* Benthic habitats

*MSFD criterion & indicators (COM May 2017):* D6C3, D6C5

The EUNIS (European Nature Information System) is the classification used in the implementation of this indicator. Originally, the indicator was tested in both broad habitats and special habitats. However, because of the characteristic of special habitats and its high sensitivity to the main pressure present in benthic habitats (trawling) it is difficult to test the indicator across a pressure gradient since the habitat disappears at highest level of trawling. Therefore, in this CEMP, we have focused the testing on broad habitats, although future testing on special habitats is planned.

*Table 1. MSFD broad habitats selected to test the SoS*

<b>HABITATS SELECTED</b>
Offshore Circalittoral Sand
Upper Bathyal Sediments
Offshore Circalittoral Mixed
Infralittoral Mud

## 2.2. Monitoring

### 2.2.1. Purpose and quantitative objectives

The purpose of this indicator is to assess the impacts of different human pressure types on the species composition of habitats through the percentage of sentinel species. Because of this, ideally the indicator requires the information obtained from monitoring programs with a coherent methodology along series, georeferenced, which obtain quantitative data of an inventory of species although if the ideal scenario is not available, the indicator is capable of using opportunist data from different surveys to assess habitat status. The minimum relevant assessment scales for SoS should be broad benthic habitats to take into consideration and minimise the natural variability of communities, which could be higher than the effects of pressure. Nevertheless, an assessment at higher detail is strongly recommended, when possible, especially for special habitats that persist within pressure gradients. Corresponding geographical scale depends both on habitat type and pressure type to be assessed.

### 2.2.2. Sampling Strategy and Quality assurance/ Quality Control

SoS indicator requires three types of data: 1) biological data (quantified species inventory), 2) environmental data, 3) pressure data

#### 1) Biological data acquisition and preparation

There are a great variability of sampling methods due to the variability of habitat morphologies. Different sampling methodologies are usually used on soft and rocky habitats. On sandy and muddy substrates, dredges, box corers and trawls are used while on rocky substrate, of them all, only video/photo and rock dredges are used to take samples. In addition, in special habitats or protected areas, only non-destructive sampling methods such as video and/or photography techniques are recommended, whereas, in predominant habitats, the use of extractive gears as dredges or trawls can be allowed. Regardless of the sampling methodology used, data should come from regular sampling or oceanographic cruises that enable continuous monitoring. Data must be at species level, georeferenced, obtained with a standardised methodology and coherent in taxonomic expertise. In general, biomass and numbers are required, although in some cases, presence could be enough (but not testing has been done with only presence/absence data). All quantitative methods are allowed: trawls, video, graze of squares, oceanographic surveys, scuba diving, etc., although merging methods in the same assessment can be problematic.

IBTS surveys are one of the most suitable existing monitoring programs which could provide data for SoS as long as invertebrate species will be identified and quantified. Currently, this survey objective is addressed in several European countries (e.g. Spain, Italy, France) but not in all of them. It is strongly recommended that DCF will include benthic objectives in their framework. WFD and Habitats Directive monitoring can also be used to obtain species inventories in their areas of influence.

#### 2) Environmental data acquisition and preparation

Environmental information is also required in order to define the benthic habitats, which at broad scale are just a combination of three environmental layers (depth, sediment type and energy). Because of the type of correlative approach used in the application of SoS to convert the pressure layer into a layer with values of the proportion of sentinel species, other environmental layers can

be included as covariates in the correlative approach. However, this possibility is not included in this CEMP guidelines for simplicity.

### 3) Pressure data acquisition and preparation

It is well known that disturbance processes from different sources (physical, biochemical, chemical, etc.) affect community structure. These processes can result from both natural and anthropogenic causes. Related to these latter causes, the human activities that can cause any type of disturbance vary depending on several factors, such as the geographical area or the substrate type. SoS is a suitable indicator for any type of pressure (including chemical and physical) limited only to the previous existence of good knowledge of species sensitivity to that pressure. In the best scenario, this knowledge will allow to group sampled species according to its sensitivity to that pressure. In this CEMP guidelines, the SoS indicator has been tested using two different pressures: trawling (applying the BESITO index, González-Irusta et al., 2018) and pollution (using AMBI groups, Borja et al., 2000).

Fishing activities is the pressure with wider distribution in the OSPAR area, and the use of standardised methods of characterisation is strongly recommended. The Vessel Monitoring System (VMS) data is needed to assess different levels of effort. The effect of pollution can be assessed for specific pollutants (e.g. Hg or organic enrichment) or can be assessed for a combination of pollutants using specific indexes. The testing was performed using the Chemical Pollution Index (CPI), which combines several different pollutants in one unique index (Bellas et al., 2011). The selection of sentinel species is based on the species present in no-pressure areas. These areas are not always easy to find, and in some cases, low-pressure areas should be used for this first step if there are not enough samples in undisturbed areas.

## 3.Data reporting, handling and management

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Actually, all datasets are produced and managed by each Contracting Parties, even for Water Framework Directive.

- *Confidence levels in data*
  - Biological data: The quality of the biological data depends largely on the sample collection and taxonomic expertise of the analysis and of the quality control for each of the monitoring networks. Hence, caution should be taken when compiling data from different sources. Spatial and temporal resolutions must be compatible with other datasets (environmental, pressure).
  - Environmental data: spatial and temporal resolutions must be compatible with other datasets (biological, pressure).
  - Pressure data: spatial and temporal resolutions must be compatible with other datasets (biological, environmental).
- *Data flows described*

Comparable monitoring programmes need to converge to produce relevant data. There are currently many gaps, both in the methods (ongoing relevant monitoring) and data availability which will difficult to test SoS for all habitats and pressure types across all OSPAR regions. Nevertheless, previous and ongoing works summarised herehave enabledthe potential of this methodology and contribution to a partial assessment.

## 4. Assessment method

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### 4.1. Parameters and metrics

The final metric of the indicator is the proportion of sentinel species. This proportion is based on the indicator analysis based on the next components:

- **Habitat data:** Ideally, the habitat which is going to be assessed has to be available in a GIS format. As a minimum, the sample data need to have information about the sampled habitat. All this information can be extracted from EMODNET if the coordinates of the samples are available.
- **Pressure data:** Ideally, the pressure will be available in a GIS format (e.g. trawling effort ICES VMS data - SAR values). As a minimum, the sample data will have information on the pressure value at the sample location.
- **Samples data:** Ideally, samples will include information on location (longitude and latitude), species abundance (biomass or number) and will be located across a complete pressure gradient (including no pressure areas). As a minimum, species abundance information across different pressure levels will be available, and if not spatial information on pressure or habitat is available, this information will be embedded in the sample information.
- **Pressure sensitivity index:** The species present in the samples data need to be sorted according to pressure sensitivity, and therefore, information about species sensitivity to the pressure needs to be directly available or extracted using an index (e.g. BESITO index). It is important to note that the BESITO index is based on traits, so this information has to be available for the species which will be included in the analysis.

In order to use the SoS indicator to assess habitat status across the pressure distribution, a map of the habitat and the pressure need to be available in a GIS format (shapefile and raster, respectively). If this information is not available, but there is the minimum information required to use the SoS indicator, this indicator can be applied to compute habitat sensitivity to the pressure as well as to assess the habitat quality in each sampled location but not to compute areas of habitat negatively affected.

### 4.2. Description of the indicator methodology

The SoS indicator determines and analyses across a pressure gradient the proportion of a set of species identified by our method as "sentinel" species. The sentinel species are selected based on a double criterion:

- 1) species frequently found in the pristine habitat (typical species) and,
- 2) species sensitive to the studied pressure (fragile species).

"Typical" species were identified using a double approach: *i)* intra-habitat similarity between stations sampled in the target habitat in areas with reference conditions (no disturbance or very low disturbance) using SIMPER (Clarke, 1993) and *ii)* relative frequency for each species inside the target habitat in reference conditions. This definition of "frequent" is based on a very intense test across different possibilities, including the use of only one of them (only frequency of occurrence or only SIMPER) and the use of different thresholds of frequency and simpler percentages. The final selection is the results of this testing and has been established as species responsible for 90% of

intra-habitat similarity within the group formed by samples in reference conditions or species present in at least 10% of the samples in reference conditions (with a minimum threshold of 2 samples). Once the "typical" species set has been determined, these species are filtered again based on its sensitivity to the pressure to select only species which are "typical" and "fragile". In this CEMP, we have used the Benthic Sensitivity Index to Trawling Operations (BESITO, González-Irusta *et al.*, 2018) for trawling disturbance and the AMBI groups (Borja *et al.* 2000) for pollution (Table 2).

Although we have only applied these indexes for these two pressures, the process to generate the list of sentinel species is the same and applicable to other pressures if species sensitive to the pressure is known. The methodology to generate the list of sentinel species is explained in Figure 1 and divided into the following steps:

1. **Step 1:** To define reference conditions using only samples located in areas with no pressure. If not enough samples in areas of no pressure are available, reference conditions can be extended to areas with low-pressure levels.

*Table 2. Summary of the indexes used to assess species sensitivity by pressure type, pollution and trawling disturbance.*

PRESSURE	INDICATOR	SCORE/GROUPS	SOS SENSITIVITY INDEX	RESPONSE
Pollution	AMBI groups (Borja <i>et al.</i> , 2000)	Groups IV, V	I	Opportunistic
		Groups II, III	II	Tolerant
		Groups I	III	Sensitive
Trawling disturbance	BESITO index (González-Irusta <i>et al.</i> , 2018)	I	I	Opportunistic
		II	II	Tolerant
		III	III	
		IV	IV	Sensitive
		V	V	

2. **Step 2:** The SoS function computes the "typical" species set, formed by species which contributes to explain the first 90% of intra-habitat similarity within the group formed by samples in reference conditions and/or species present in more than 10% of the samples (rounded) in reference conditions with a minimum threshold of 2 samples.
3. **Step 3:** All the species with a SoS sensitivity index of 5 (see table 2 for equivalences with BESITO or AMBI groups) are selected for the total species set. The species are selected one by one, selecting first species from SIMPER and then species which pass the frequency threshold. If, after selecting the species with a sensitivity index of 5 from the SIMPER, the

number of sentinel species is 10 or higher, the function stops, being the sentinel species, the species already selected. If the number of sentinel species is lower than 10, it starts to select species which pass the frequency threshold in decreasing order of frequency. If, during the selection of these species, the number of sentinel species reaches the number of 10 sentinel species, the function stops adding to the final list of sentinel species all the species of sensitivity 5 with the same frequency that the last species added. Otherwise, the function continues in step 4. It is important to highlight that since for pollution, there are not values higher than 3 for the SoS sensitivity index, the function starts directly in step 5 when SoS is using to assess pollution effects.

4. **Step 4:** This step repeats the procedure of step 3 but adding to the list of sentinel species already generated in step 3 new species with a SoS sensitivity index of 4. If after adding the species from the SIMPER or which pass the frequency threshold, the number of sentinel species reaches the number of 10, the function stops as was described in step 3; otherwise, the function continues in step 5.
5. **Step 5:** This step repeats the procedure of steps 3 and 4 but adding to the list of sentinel species already generated in previous steps new species with a SoS sensitivity index of 3. If, after adding the species by SIMPER or by frequency, the number of sentinel species is 5 or higher, the function stop and the sentinel species are the species already selected; otherwise, the function continues in step 6. It is important to highlight that in this step, the threshold of sentinel species required to stop the function is 5 instead of 10. The reason for this is that species with a SoS sensitivity index lower than 3 are tolerant to the pressure not sensitive, and then, his inclusion has been limited only to habitats where sensitive species are not present or are very scarce.
6. **Step 6:** This step repeats the procedure of step 3 but adding to the list of sentinel species already generated in step 3 new species with a SoS sensitivity index of 2. The function stops as soon as the number of sentinel species is 5 or when all species with a sensitivity of 2 have been included.

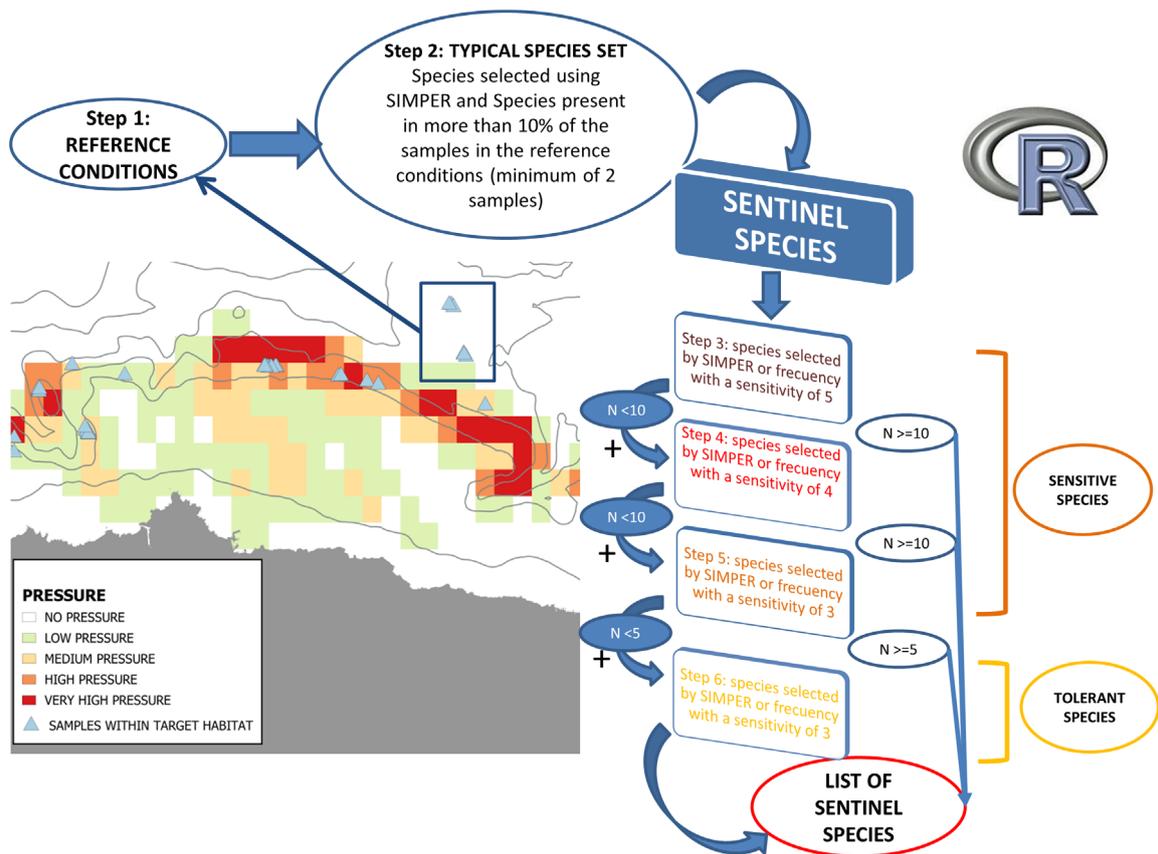


Figure 1. Diagram explaining the methodology to determine the sentinel species list. All these steps have been included in an R function publicly available at <https://github.com/Gonzalez-Irusta/SoS>

## 5. List of annexes

### 5.1. Annex 1 –Data selected for testing Sentinels of the Seabed Indicator (SoS)

In view of the criteria defined in this report and having regard to data availability, we selected the following data:

Table 3. Data selected to test the SoS for each case study.

Habitatsselected	Case study	Sampler	Disturbance
Offshore Circalittoral Sand	I- Demersales OCS	Otter trawl	Physical- Fishing- Trawling
Upper Bathyal Sediments	II- Demersales UBS	Otter trawl	Physical- Fishing- Trawling
Offshore Circalittoral Mixed Sediment	III- Demersales OCMix	Otter trawl	Physical- Fishing- Trawling
Infralittoral Mud	V- Ría de Vigo	Box-corer	Chemical pollution

#### 5.1.1. "Demersales" IBTS survey case Studies (I,II and III)

Demersales is the name of the Spanish bottom trawl survey that each autumn (September-October) since 1983 has been carried out by the Spanish Institute of Oceanography (IEO) in the south of the Bay of Biscay. These surveys are standardised by ICES protocol (IBTS working group) and based on random stratified sampling (by depth and geographic strata) and consist of 30 min hauls which are towed at a speed of 3.0 knots, using the otter trawl Baca 44/60 gear (Sánchez & Serrano, 2003; Serrano et al., 2011). The survey is carried out on the north coast of Spain, from the border with Portugal to the border with France (Figure 2) in a wide range of different seabed habitats on soft bottoms. Five depth strata (<70, 70–120, 120–200, 200–500 and >500 m) are defined in these surveys. The number of hauls per stratum is proportional to the surface area available for trawling. All species caught (including invertebrates) are identified, counted, and weighed in each haul. Although invertebrate data since 2003 are available, in order to assure a good concordance between the biological data and the fishing effort (available only for the period 2009 to 2019), we limited the analysis to the period 2013 to 2019.

A very wide range of species are caught, including species which are not interesting in the definition of this indicator, such as pelagic species, species with identification problems across the historical series or infrequent species (frequency < 1% of the total set of species). Moreover, fishes were eliminated from the analysis since we considered that, in general, they could have a lower relationship with the sea bed habitat than invertebrates, although the possibility of include benthic fish species in future work is not discarded. In total, 133 different species providing 79% of the total invertebrate biomass caught in the Demersales hauls were assigned with biological traits and therefore were available to be classified in one of the sensitivity BESITO groups.

### 5.1.1.1 Habitats selected

DEMERSALES survey comprehends several MSFD broad habitats, and three of those habitats were selected for testing the SoS indicator; offshore circalittoral sand, upper bathyal sediment and offshore circalittoral mixed sediment. Table 4 shows the correspondence of these MSFD broad habitats with EUNIS level 3 and Figure 2 their distribution in the study area.

*Table 4. MSFD habitats most sampled in DEMERSALES surveys with its depth range, the number of hauls by habitat, its equivalence in EUNIS 3 habitats, and the percentage of the total trawling footprint carried out within each habitat.*

MSFD habitat	EUNIS Habitat	EUNIS code	Sampled Depth	Number of hauls	Percentage of trawling footprint within each habitat
Offshore circalittoral sand	Deep circalittoral sand	A5.27	>70 & ≤ 200 m	140	25.27%
Offshore circalittoral mixed sediment	Deep circalittoral mixed sediments	A5.45	>70 & ≤ 200 m	97	2.27%
Upper bathyal sediment	Deep-sea muddy sand	A6.4	>200 & ≤ 800 m	346	32.65%
	Deep-sea sand	A6.3			
	Deep-sea mixed substrata	A6.2			

Although 16 different EUNIS 3 habitats have been sampled during the study period for the Demersales survey, only five were sampled with enough frequency to be included in the analysis (Table 4). These five habitats were distributed in two depth strata: offshore circalittoral and upper bathyal (> 200 m deep), and correspond with the three MSFD broad habitat types selected. These habitats were also distributed in four sediment types; mud, muddy sand, sand and mixed substrata. Despite being only three MSFD broad habitats, they cover an important part of the total trawling footprint in the area (60%).

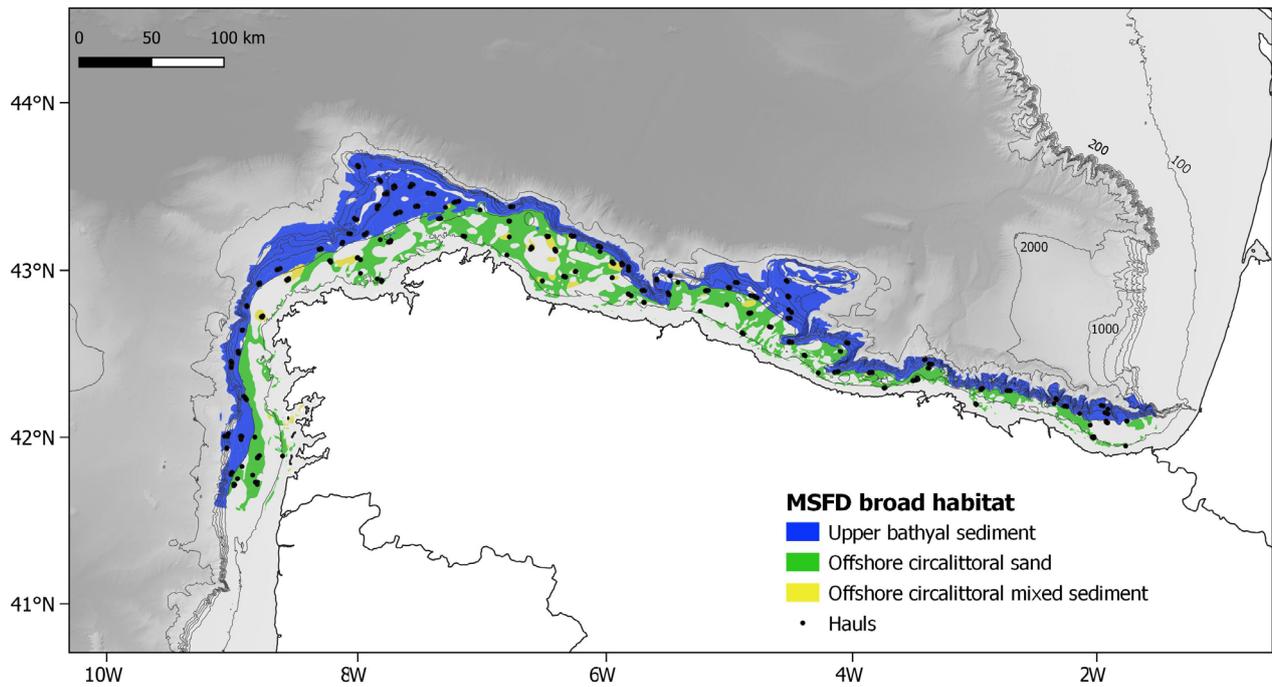


Figure 2. Distribution of the MSFD habitats most sampled in DEMERSALES surveys in the north coast of Spain.

#### 5.1.1.2 Disturbance: trawling

The fishing effort was assessed using the Vessel Monitoring System (VMS), which supplies GPS locations from the fishing vessels longer than 12 m every 2 hours and logbook data (gear information). Gear and GPS location data were linked using ship code and trip date fields. VMS pings not related to fishing activity were removed using speed and other criteria (Punzón et al., 2016). In order to compute fishing effort maps, we calculated the swept area ratio: hauls were assigned to individuals fishing trips, and VMS pings were interpolated to obtain the fishing track of each haul using the cubic-hermite spline interpolation (Hintzen et al., 2010). The swept area was calculated by a c-square resolution ( $0.05^\circ$ ) for the Spanish trawling fleet during the period analysed (2009-2019) (Figure 4).

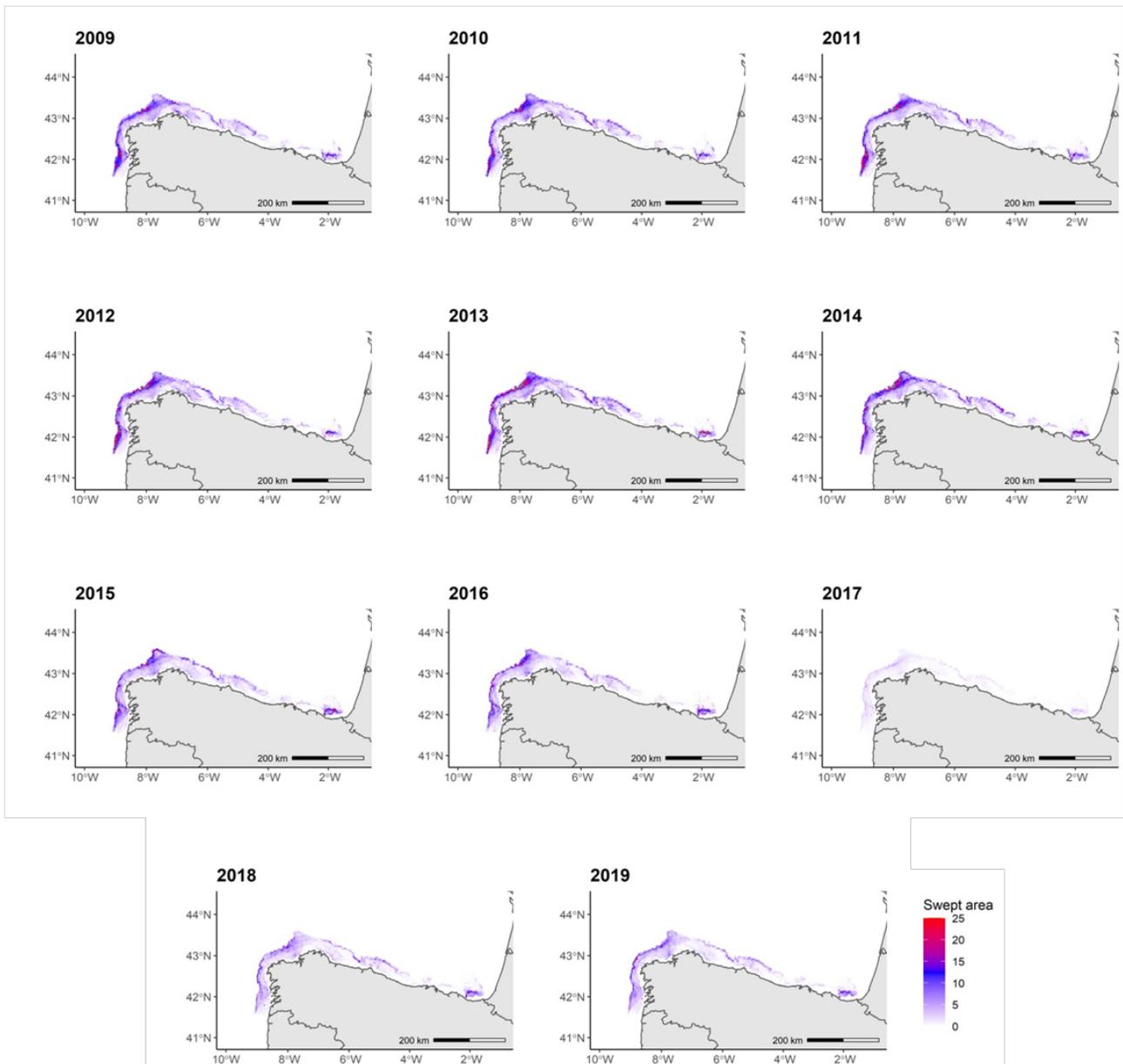


Figure 3. Trawling effort (SAR values) for year. These data are only Spanish data; therefore, they differ from the data applied to the BH1 assessment. Results between these CEMP guidelines and the BH1 assessment are obtained with slightly different pressure data and may differ.

The trawling effort (SAR, swept area ratio) for each haul was computed as the mean fishing effort for the 4 previous years, including the year when the biological samples were taken (Example: for the biological data sampled in 2013, we used the mean fishing effort for the period 2009-2013). The final mean trawling effort values were pooled in 5 levels of trawling effort; No effort-very low effort ( $0 \leq \text{SAR} \leq 0.33$ ), low effort ( $0.33 < \text{SAR} \leq 1$ ), medium effort ( $1 < \text{SAR} \leq 4$ ), high effort ( $4 < \text{SAR} \leq 10$ ) and very high effort ( $\text{SAR} > 10$ ).

The hauls made on the target habitat and in areas with very low effort were selected to select the Sentinel species. Then the relative abundance of these species was computed across the different levels of disturbance following the methodology previously described.

To assess the area of each habitat severely affected by trawling (annex 2), the period 2013-2019 was selected, and the mean of the fishing effort (mean SAR value) for this period was used. Figure 3 shows each year's fishing effort (SAR values), and Figure 4 shows the mean value for 2013-2019.

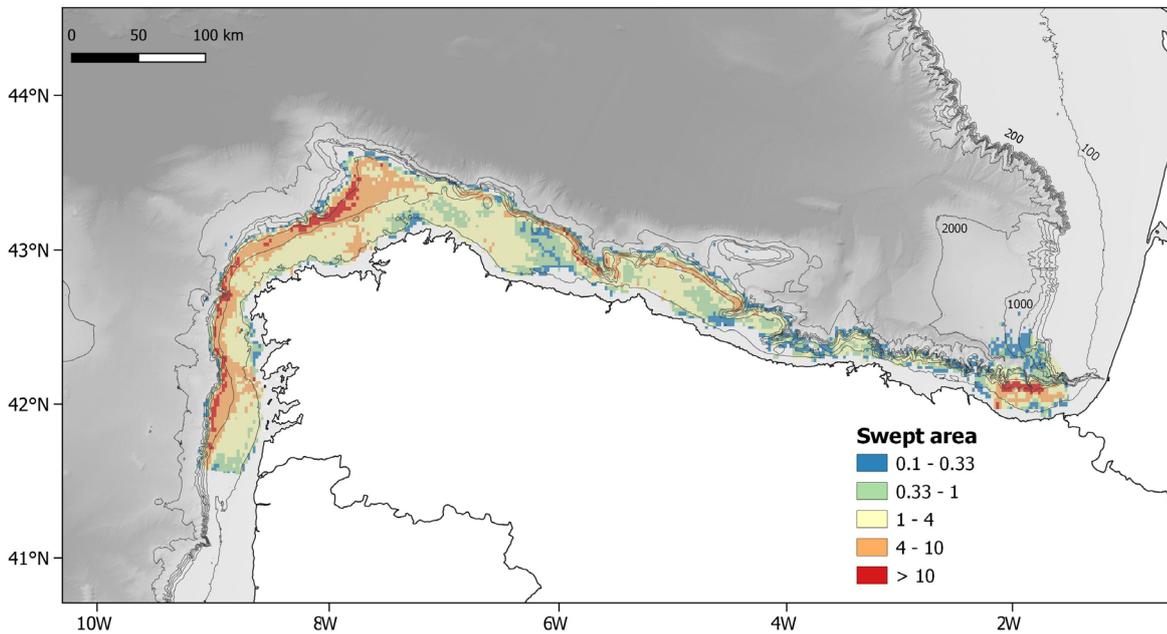


Figure 4. SAR values for the period 2013-2019 obtained by the mean of this trawling period.

#### 5.1.2. Ría de Vigo case Study (V)

In the present case study, we have applied SoS to a set of stations distributed across the "Ría de Vigo" (NW Iberian Peninsula, Figure 5). The data set is part of a multi-year monitoring effort developed in the context of the project FERRAMENTAS (Beiras et al., 2012). The data set is formed by 20 different stations distributed across the estuary. The biological communities were sampled in each station using a modified BOUMA box corer with a sampling area of 0.0175 m<sup>2</sup>. The samples were sieved on board through a 0.5 mm sieve.

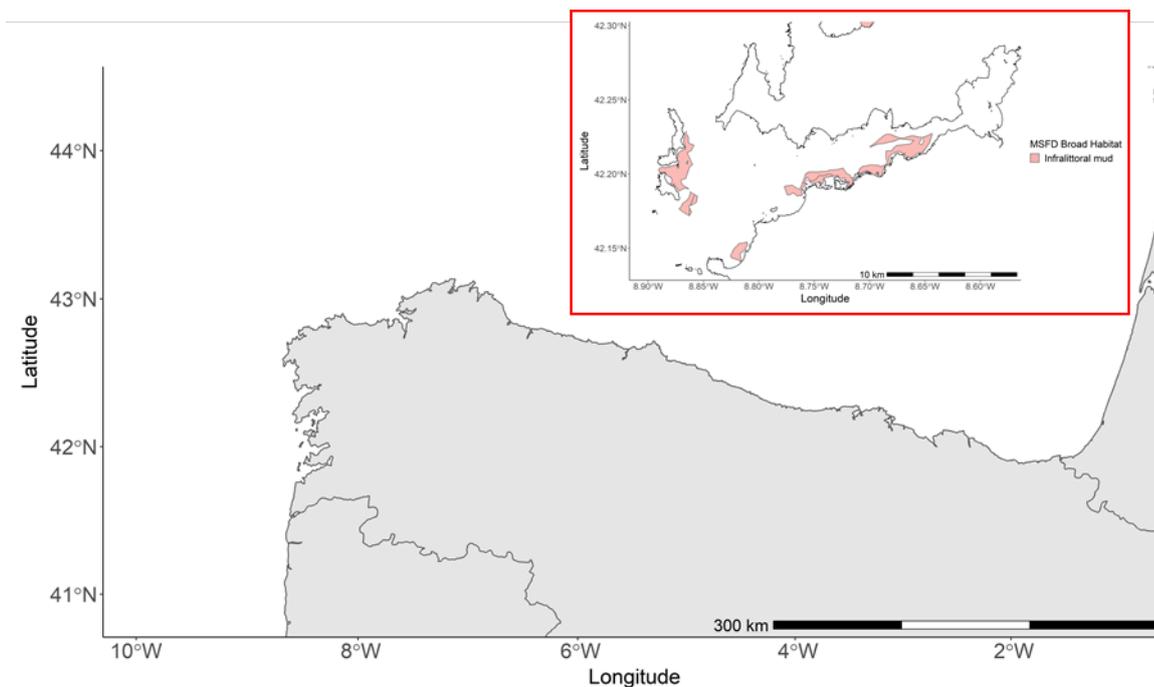


Figure 5. Location of the study area (Ría de Vigo, NW Spain) and the distribution of the infralittoral mud MSFD broad habitat.

Furthermore, than the biological samples, particle size, organic matter, heavy metals and other pollutants were also quantified. More details about the exact methods applied can be consulted in Beiras et al. (2012). The 20 box corer analysed were distributed across 6 locations, between 4 and 20 m depth. All of them were distributed in the infralittoral mud habitat. In order to pool all the pollutants in one unique pressure value, we used the CPI index, which combines in one unique value a matrix of contaminants (Bellás et al., 2011; Beiras et al., 2012). The CPI values in the stations ranged from  $-1.84$  to  $7$ , being the stations with values  $< 0$  considered not polluted stations (Table 5).

The CPI values were pooled in 5 levels of pressure; no pollution ( $CPI \leq 0$ ), low pollution ( $>0 \ \& \ \leq 1$ ), medium pollution ( $>1 \ \& \ \leq 2.5$ ), high pollution ( $>2.5 \ \& \ \leq 4$ ) and very high pollution ( $>4$ ). These stations ( $CPI < 0$ ) were used to obtain the sentinel species using the methodology described before.

For this case study, we have used the classification applied in the AMBI index (Borja et al., 2000), which classified the species with values from 1 (sensitive) to 5 (first-order opportunistic). In normal circumstances, only species classified as Group I ("species very sensitive to organic enrichment, present under unpolluted conditions") should be considered as sentinel species. However, in areas with a high level of pollution, species from Group II (species indifferent to enrichment, always present in low densities) and III (species tolerant to excess organic matter) can be added (see Table 2).

Table 5. Summary of the different pollutants values used to compute the Chemical Pollution Index values (Bellás et al., 2011).

	<b>Hg</b>	<b>Cu</b>	<b>Zn</b>	<b>Cd</b>	<b>Pb</b>	<b>Cr</b>	<b>As</b>	<b>Σ8PAH</b>	<b>Σ7PCB</b>	<b>ΣDDT</b>	<b>CPI</b>
CA0406	0.14	29.10	132.00	0.08	67.00	67.50	18.44	362.03	17.01	1.35	-1.84
CA1004	0.15	33.30	127.00	0.14	77.70	85.20	15.50	396.71	12.95	1.21	-1.57
CA0305	0.19	37.20	180.00	0.17	76.10	83.60	19.80	326.15	10.62	0.71	-1.51
MO0304	0.30	43.59	151.25	0.38	44.81	81.10	16.99	850.76	15.62	1.50	-0.36
MO0406	0.22	46.70	150.00	0.20	89.30	86.60	18.93	708.07	17.64	1.96	-0.28
MO0305	0.29	49.20	177.00	0.30	82.50	92.90	22.00	939.60	20.39	1.53	0.24
MO1004	0.24	47.90	144.00	0.44	110.00	102.00	20.60	718.16	21.46	2.03	0.40
RE0305	0.46	54.70	169.00	0.57	112.00	67.60	18.30	1003.01	12.29	2.64	0.71
RE0406	0.32	55.10	178.00	0.53	185.00	76.30	15.89	746.52	21.25	2.97	0.91
RE0304	0.43	54.48	190.07	0.61	124.17	75.13	13.72	889.99	21.11	3.58	1.04
RE1004	0.35	50.50	157.00	0.70	169.00	81.20	16.90	769.90	20.49	5.31	1.24
AG0304	0.49	75.03	241.08	0.50	63.03	88.06	22.74	1262.11	51.87	3.89	1.82
AG1004	0.35	73.60	218.00	0.52	139.00	102.00	21.20	1911.64	59.84	4.38	2.31
AG0406	0.53	70.30	216.00	0.49	96.40	81.80	24.81	1525.28	95.41	6.66	2.54
AG0305	0.49	82.80	264.00	0.46	128.00	86.40	24.90	1159.49	131.99	5.06	2.70
VI1004	0.41	199.00	510.00	0.70	117.00	74.40	27.60	1278.81	97.56	16.46	3.83
NA0406	1.96	367.00	299.00	0.64	305.00	50.30	9.41	8500.92	79.52	64.56	5.61
VI0305	0.77	321.00	1530.00	1.43	216.00	111.00	46.30	2042.93	163.85	23.61	6.34
VI0406	0.71	363.00	1021.00	1.30	217.00	102.00	46.78	2298.36	251.34	34.89	6.52
NA0305	2.60	205.00	1061.00	1.79	496.00	110.00	22.10	11775.71	58.41	133.56	7.72

From the original list of 244 taxa, 183 (75%) were in the AMBI list and could be classified into one of the five described groups. These 183 taxa were 92% of the total individuals counted, so practically all the analysed species were included in the testing. From the 20 stations analysed in this case study, 5 had CPI values < than 0 (not polluted) and were used to obtain the list of sentinel species.

## 5.2. Annex 2 –Application of SoS indicator to assess the area of each habitat severely affected by trawling

The SoS indicator can be directly applied to assess D6C3 by converting the pressure maps into the percentage of sentinel species using correlative approaches. The correlation between the proportion of sentinel species and trawling effort (SAR values) was analysed using General Additive Models (GAMs). Since the response data was a proportion from 0 to 1, it was analysed using a binomial GAM with Logit as link function (Zuur et al., 2009). Although in the interest of simplicity in this example, other covariates (depth, sediment type, temperature, etc.) were not included in the models, it is important to note that they can be included if needed.

The statistical models were then applied to the GIS layers of trawling effort after masking them to the extent of each habitat extension polygons to generate a geographical prediction of sentinel species proportion across the habitat. Then these values were converted into the degree of disturbance of the habitats (habitat status) by using a quality threshold specific for each habitat (minimum proportion of sentinel species acceptable to keep ecosystem processes). The areas were classified as follows:(i) GES when the proportion of sentinel species was higher than the threshold, even after removing the standard error(uncertainty of the model ); (ii) NO GES when the proportion of sentinel species was minor than the threshold, even after adding the standard error and (iii) Uncertain areas when the position (higher or lower) of the proportion of sentinel species related to the threshold changes after adding/removing the standard error. Therefore, as long as the seabed

habitats were under trawling pressure (SAR values > 0), they would be disturbed to a greater or lesser degree based on their pressure-state curves. The total area of each category was computed for each year and across the period. Currently, there is no agreement in quality thresholds, and although some methods to compute these values are being proposed (see annex III), there are not definitely agreed methods. Therefore, in these CEMP guidelines, a value of 0.5 for all habitats has been chosen as the quality threshold for demonstration purposes only. In this sense, even when the term GES is mentioned occasionally, this is not real GES but only an example on how these areas will be classified after agreeing on the quality threshold, something unfortunately not possible at the moment.

### 5.2.1 Case study I. Offshore Circalittoral Sand habitat

The Offshore Circalittoral Sand (OCS) habitat is the most common circalittoral MSFD broad habitat in the study area (Figure 2) and the second most extent in the region after the upper bathyal sediment. This habitat is present across the area, from the border with France to the border with Portugal, and it has been well sampled across the depth range from 70 to 200 m. Twelve species were selected as the OCS habitat sentinel species (Table 6). From the twelve, one species (the sponge *Phakellia ventilabrum*) has a sensitivity of 5, two species (the ascidia *Corella parallelogramma* and the sea-pen *Funiculina quadrangularis*) have a sensitivity of 4, and the other nine species have a sensitivity of 3. The variation in the proportion of sentinel species across the trawling gradient is shown in Figure 6. The SoS indicator showed a negative and statistically significant relationship with trawling effort (Rho=-0.39 p-val<0.001). Around 70% of total biomass was represented by sentinel species in no-pressure areas, while values turned close to 0 in areas exposed to high levels of SAR. Other frequent metrics used to measure trawling impacts are also shown in Figure 6, including Total biomass, richness and Shannon index. From them, only total biomass had a significant relationship with trawling, although the correlation was weaker (Rho=-0.28, p-val<0.001) than for the SoS indicator.

Table 6. Sentinel species composition for the OCS habitat.

SENSITIVITY	SENTINEL SPECIES
5	<i>Phakellia ventilabrum</i>
4	<i>Corella parallelogramma</i> , <i>Funiculina quadrangularis</i>
3	<i>Gracilechinus acutus</i> , <i>Ophiothrix fragilis</i> , <i>Parastichopus regalis</i> , <i>Actinauge richardi</i> , <i>Spatangus purpureus</i> , <i>Anseropoda placenta</i> , <i>Echinus melo</i> , <i>Leptometra celtica</i> , <i>Nymphaster arenatus</i>

The correlation between the proportion of sentinel species and SAR was also analysed using binomial General Additive Models (GAMs). The model explained 14 % of total deviance, and the correlation between both variables was statistically significant (p-val<0.01, Table 7).

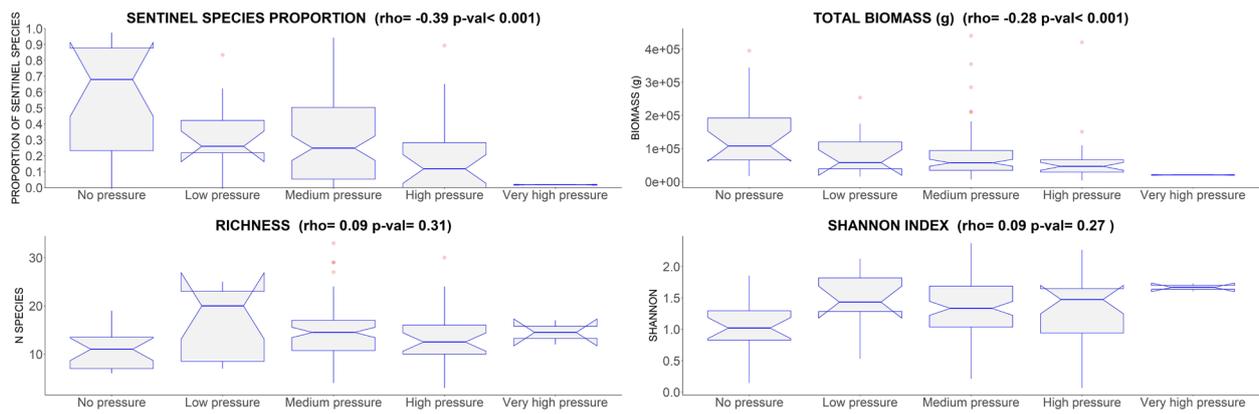


Figure 6. Proportion of sentinel species, Total biomass, Richness and Shannon index for the OCS habitat. Number of hauls per pressure level: No pressure=19, Low pressure=11, Medium pressure=84, High pressure=24, very high pressure=3

Table 7. GAM summary for the OCS habitat.

Deviance explained (%)			
GAM = $\beta_1 + s(\text{trawling effort}) + \epsilon_1$			14.0
	edf	Chi-square	p-val
<b>Trawling effort</b>	1	7.1	<0.01

The shape of this relationship is shown in Figure 7. Both variables showed an inverse relationship, with a sharp negative slope in the first and medium values of effort and soften when reaching higher values. The observed correlation was used to generate areas of proportion of sentinel species in base to the fishing effort layer (Figure 7A) and then compute the level of disturbance of the areas in base to a threshold. In this case, we used the value 0.5 for demonstration purposes, but in the future, the quality threshold will be specifically determined based on the shape of the response curve (see Annex 3 and 4).

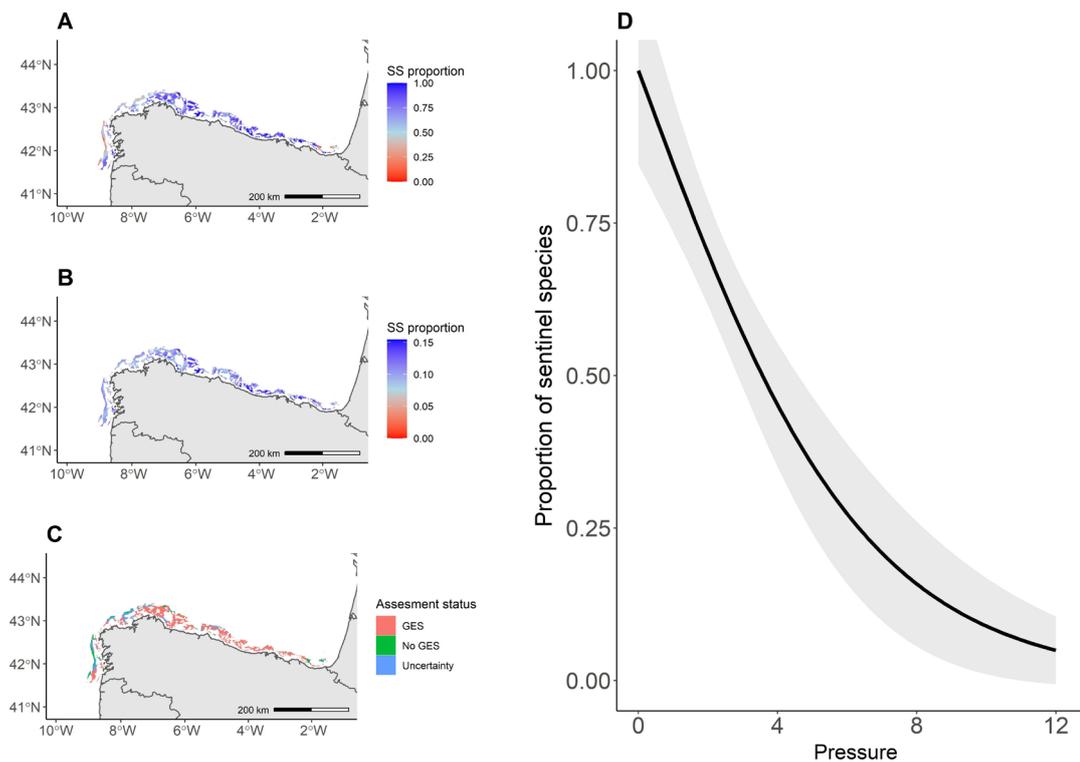


Figure 7.A) Predicted proportion of sentinel species across the MSFD habitat B) Standard error (SE) associated with the prediction C) Areas in Good Environmental Status (proportion of sentinel species >0.5 regardless SE values), Areas with not Good Environmental Status (proportion of sentinel species <0.5 regardless SE values) and uncertain areas (the relative value of the proportion of sentinel species in relation with the threshold vary with the SE D) GAM response curve showing the relation between the proportions of sentinel species and trawling effort (SAR values).  
 Table 8. Summary of assessment statistics for the OCS habitat.

The uncertainty of the model was spatially represented in Figure 7B and was taken into account when classifying the areas into GES, NO GES or uncertain areas. Thus, GES areas were considered when the proportion of sentinel species was higher than the threshold even after removing the standard error, No GES areas when the proportion of sentinel species was minor than the threshold even after adding the standard error and Uncertain areas when the position (higher or lower) of the proportion of sentinel species related to the threshold changes after adding/removing the standard error. We only considered as GES areas the first case explained, although Table 8 shows this data broken down by years and by the 3 categories. From the 7644 km<sup>2</sup> seabed areas with OCS habitat, 5556 km<sup>2</sup> (72.68%) showed values in the proportion of sentinel species higher than 0.5 for 2013-2019 and therefore were classified as in GES. These values are only for demonstration purposes and do not have management value.

Total area of OCS (km <sup>2</sup> )	Year/s	Environmental assessment status	Area (km <sup>2</sup> )	Proportion of total area (%)
7644	2013-2019	GES	5556	72.68
		No GES	679	8.88
		Uncertain	1409	18.43
	2013	GES	4275	55.93
		No GES	1889	24.71
	2014	Uncertain	1480	19.36
	2014	GES	4780	62.53

	No GES	1440	18.84
	Uncertain	1424	18.63
2015	GES	5272	68.97
	No GES	1170	15.31
	Uncertain	1202	15.72
2016	GES	5782	75.64
	No GES	725	9.48
	Uncertain	1137	14.87
2017	GES	7604	99.48
	No GES	2	0.03
	Uncertain	38	0.5
2018	GES	6094	79.72
	No GES	631	8.25
	Uncertain	919	12.02
2019	GES	6359	83.19
	No GES	354	4.63
	Uncertain	931	12.18

### 5.2.2 Case study II. Offshore Upper Bathyal Sediments habitat

The upper bathyal sediment (UBS) habitat is the most common MSFD broad habitat in the study area, distributed with big patches all across the north coast of Spain (Figure 3). The patches are the smallest in the eastern part because the narrow slope in this area, whereas reach maximum size in the Galician slope, in the northwest part.

Eleven species were selected as sentinel species of the UBS habitat (Table 9). The first three species from the list were highly sensitive (sensitivity of 5), including two sponges (*Asconema setubalense* and *Phakellia ventilabrum*) and the "bamboo coral" *Acanella arbuscula*. Then, two sea-pens, *Funiculina quadrangularis* and *Kophobelemnon stelliferum* with sensitivity 4, were selected, and the other seven were species of sensitivity 3.

Table 9. Sentinel species composition for the UBS habitat.

SENSITIVITY	SENTINEL SPECIES
5	<i>Asconema setubalense</i> , <i>Acanella arbuscula</i> , <i>Pheronema carpenteri</i> ,
4	<i>Funiculina quadrangularis</i> , <i>Kophobelemnon stelliferum</i>
3	<i>Actina gerichardi</i> , <i>Nymphaster arenatus</i> , <i>Parastichopus tremulus</i> , <i>Araeosoma fenestratum</i> , <i>Hymenodiscus coronata</i> , <i>Gracilechinus acutus</i>

The correlation between the percentage of typical species and trawling effort was significant and negative (Spearman coefficient:  $Rho = -0.58$   $p\text{-val} < 0.001$ ), Figure 8 shows this decreasing proportion of sentinel species with increasing trawling effort. This habitat showed an initial value of 55% in the proportion of sentinel species of total biomass in no-pressure areas and values close to zero in the high and very high-pressure areas. An acute descent appears for no pressure with respect to low pressures values, and then it continues to descend. Other frequent metrics used to measure trawling impacts are also shown in Figure 8, including Total biomass, richness and Shannon index. Although

other metrics also had a significant relationship with trawling, the trend was less clear, and the correlation was weaker in all cases or even positive for total biomass.

The correlation between the proportion of sentinel species and trawling effort was also analysed using binomial General Additive Models (GAMs). The model explained 29.9% of total deviance, and the correlation between both variables was statistically significant ( $p\text{-val} < 0.001$ , Table 10). The shape of this relationship is shown in Figure 9. Both variables showed an inverse relationship, with a negative sharp slope in the first values of effort and soften when reaching higher values of fishing effort until it almost completely flattens in the highest values. The observed correlation was used to predict the proportion of sentinel species in base to the fishing effort layer (Figure 9A) and then compute areas in GES in base to a threshold. In this case, we used the value 0.5 for demonstration purposes.

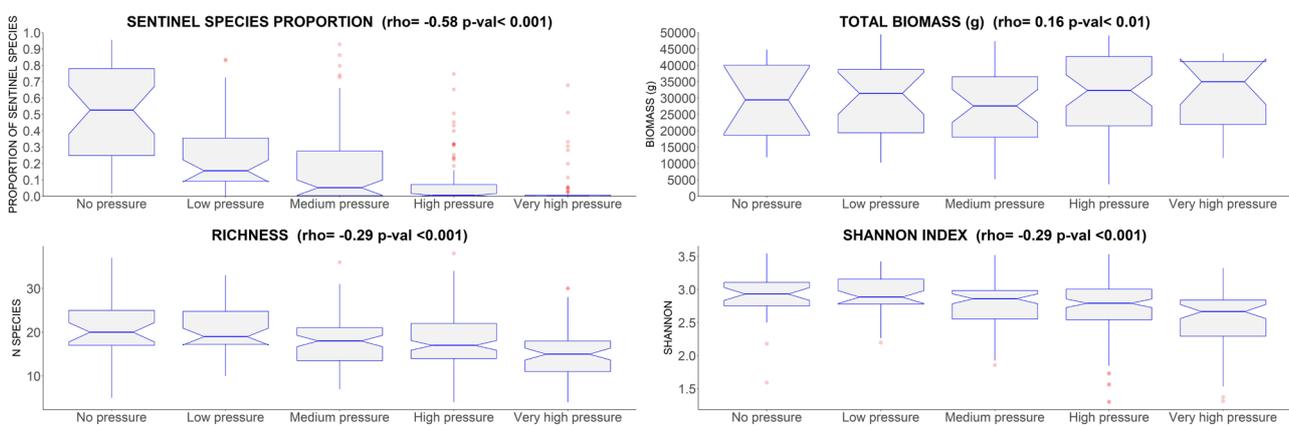


Figure 8. Proportion of sentinel species, Total biomass, Richness and Shannon index for the UBS habitat. Number of hauls per pressure level: No pressure=33, Low pressure=38, Medium pressure=83, High pressure=127, very high pressure=65.

Table 10. GAM summary for the UBS habitat.

Deviance explained (%)			
GAM = $\beta_1 + s(\text{trawling effort}) + \epsilon_1$		29.9	
	edf	Chi-square	p-val
<b>Trawling effort</b>	1	32.74	<0.001

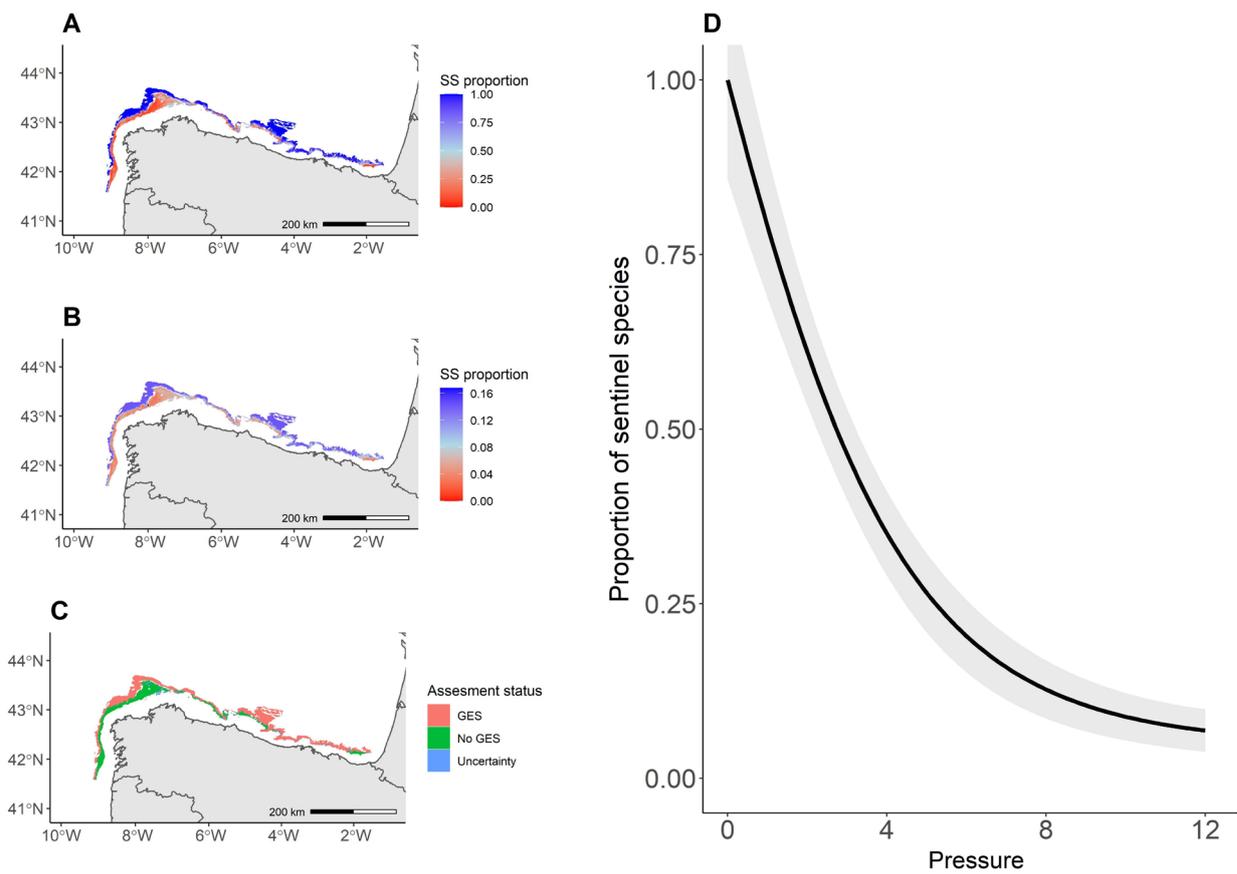


Figure 9.A) Predicted proportion of sentinel species across the MSFD habitat B) Standard error (SE) associated to the prediction C) Areas in Good Environmental Status (proportion of sentinel species >0.5 regardless SE values), Areas with not Good Environmental Status (proportion of sentinel species <0.5 regardless SE values) and uncertain areas (the relative value of the proportion of sentinel species in relation with the threshold vary with the SE D) GAM response curve showing the relation between the proportions of sentinel species and trawling effort ( SAR values).

The uncertainty of the model (standard error) was also spatially represented in Figure 9B and had been taken into account when classifying the areas into GES, No GES or Uncertain areas. Thus, GES areas were considered when the proportion of sentinel species was higher than the threshold even after removing the standard error, No GES areas when the proportion of sentinel species was minor than the threshold even after adding the standard error and Uncertain areas when the position (higher or lower) of the proportion of sentinel species related to the threshold changes after adding/removing the standard error. We considered as GES areas only the first case explained, but Table 11 shows this data broken down by years and by the 3 categories. From the 13117 km<sup>2</sup> seabed areas with upper bathyal sediment, 8029 km<sup>2</sup> (61.21%) showed values in the proportion of sentinel species higher than 0.5 for 2013-2019 and therefore were classified as in GES. These values are only for demonstration purposes and do not have management value.

Table 11. Summary of assessment statistics for the UBS habitat.

Total area of UBS (km <sup>2</sup> )	Year/s	Environmental assessment status	Area by category (km <sup>2</sup> )	Proportion of total area by category (%)
13117	2013-2019	GES	8029	61.21
		No GES	4473	34.1

	Uncertain	615	4.69
2013	GES	7805	59.5
	No GES	4684	35.71
	Uncertain	628	4.79
2014	GES	7635	58.21
	No GES	4959	37.81
	Uncertain	523	3.99
2015	GES	7948	60.59
	No GES	4416	33.67
	Uncertain	753	5.74
2016	GES	8461	64.5
	No GES	3942	30.05
	Uncertain	714	5.44
2017	GES	12265	93.5
	No GES	353	2.69
	Uncertain	499	3.8
2018	GES	8910	67.93
	No GES	3239	24.69
	Uncertain	968	7.38
2019	GES	8323	63.45
	No GES	3709	28.28
	Uncertain	1085	8.27

### 5.2.3 Case study III. Offshore Circalittoral Mixed Sediment habitat

The offshore circalittoral mixed sediments (OCMix) habitat is not common in the study area and shows a patchy distribution in small areas across the north coast of Spain (Figure 2). The biggest patches are located in Galician waters (NW Spain), between the capes of Estaca and Finisterre, and the habitat is very scarce in the inner part of the Bay of Biscay, with only a few small patches in the eastern part of the study area.

Table 12. Sentinel species composition for the OCMix habitat.

SENSITIVITY	SENTINEL SPECIES
4	<i>Corella parallelogramma</i>
3	<i>Parastichopus regalis</i> , <i>Gracilechinus acutus</i> , <i>Actinaugerichardi</i> , <i>Ophiothrix fragilis</i>

Five species were selected as sentinel species of the OCMix Sediment habitat (Table 12). The ascidia *Corella parallelogramma* with sensitivity 4 and four species of sensitivity 3. The correlation between the percentage of typical species and trawling effort was significant and negative (Spearman coefficient:  $Rho = -0.52$   $p\text{-val} < 0.001$ ).

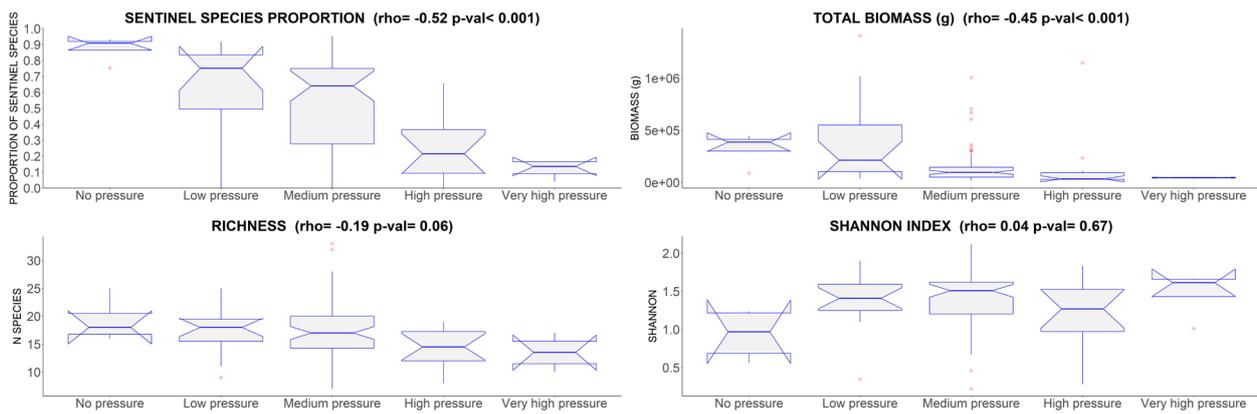


Figure 10. Proportion of sentinel species, Total biomass, Richness and Shannon index for the OCMix habitat. Number of hauls per pressure level: No pressure=4, Low pressure=15, Medium pressure=62, High pressure=12, very high pressure=4.

Figure 10 shows this decreasing proportion of sentinel species with increasing trawling effort. This habitat showed initial values close to 90% in the proportion of sentinel species of total biomass in no pressure and close to 75% in low pressures areas, with an acute decrease in high-pressure areas to 20%. Other frequent metrics used to measure trawling impacts are also shown in Figure 10, including Total biomass, richness and Shannon index. Only total biomass had a significant relationship with trawling, although the correlation was weaker (Rho=-0.45, p-val<0.001).

The correlation between the proportion of sentinel species and trawling effort was also analysed using binomial General Additive Models (GAMs). The model explained 25.8% of total deviance, and the correlation between both variables was statistically significant (p-val<0.01, Table 13). The shape of this relationship is shown in Figure 10D. Both variables showed an inverse relationship, with a soft slope when reaching higher values of fishing effort. The observed correlation was used to generate areas of proportion of sentinel species in base to the fishing effort layer (figure 10A) and then compute areas in Good Environmental Status (GES) in base to a threshold. In this case, we used the value 0.5 for demonstration purposes.

Table 13. GAM summary for the OCMix habitat.

Deviance explained (%)			
GAM = $\beta_1 + s(\text{trawling effort}) + \epsilon_1$			25.8
	edf	Chi-square	p-val
<b>Trawling effort</b>	1	7.76	<0.01

The uncertainty of the model (standard error) was also spatially represented in Figure 9B and had been taken into account when classifying the areas into GES, No GES or Uncertain areas. Thus, GES areas were considered when the proportion of sentinel species was higher than the threshold even after removing the standard error, No GES areas when the proportion of sentinel species was minor than the threshold even after adding the standard error and Uncertain areas when the position (higher or lower) of the proportion of sentinel species related to the threshold changes after adding/removing the standard error. We considered as GES areas only the first case explained, but Table 14 shows this data broken down by years and by the 3 categories. From the 669 km<sup>2</sup> seabed areas with upper bathyal sediment, 519 km<sup>2</sup> (77.58%) showed values in the proportion of sentinel species higher than 0.5 for the period 2013-2019 and therefore were classified as in GES.

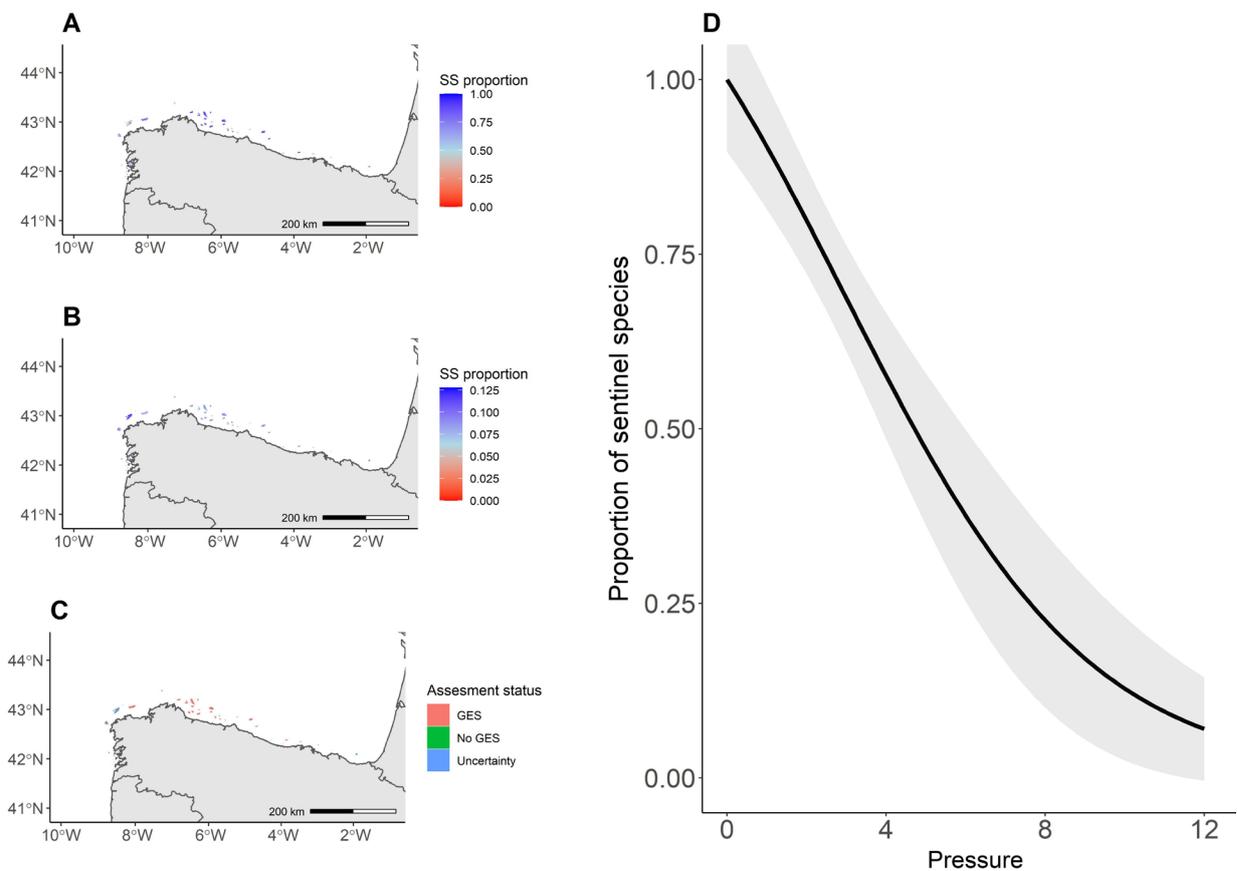


Figure 11. A) Predicted proportion of sentinel species across the MSFD habitat B) Standard error (SE) associated to the prediction C) Areas in Good Environmental Status (proportion of sentinel species >0.5 regardless of SE values), Areas with not Good Environmental

Table 14. Summary of assessment statistics for the OCMix habitat.

Total area of OCMix(km <sup>2</sup> )	Year/s	Environmental assessment status	Area by category (km <sup>2</sup> )	Proportion of total area by category (%)
669	2013-2019	GES	519	77.58
		No GES	27	4.04
		Uncertain	123	18.39
	2013	GES	471	70.4
		No GES	102	15.25
		Uncertain	96	14.35
	2014	GES	472	70.55
		No GES	107	15.99
		Uncertain	90	13.45
	2015	GES	495	73.99
		No GES	65	9.72
		Uncertain	109	16.29
	2016	GES	498	74.44
		No GES	45	6.73
		Uncertain	126	18.83
	2017	GES	668	99.85
		No GES	1	0.15
		Uncertain	0	0
	2018	GES	558	83.41
		No GES	34	5.08
		Uncertain	77	11.51
2019	GES	603	90.13	
	No GES	24	3.59	
	Uncertain	42	6.28	

#### .2.4 Case study V. Infralittoral Mud habitat

The Infralittoral Mud (IM) habitat is concentrated on the southern part of the Ria and the east side of the Cies islands within the Ria de Vigo study area (Figure 5). Ten species were selected as sentinel species of the IM habitat (Table 15). All of them were classified as group 3 in the AMBI indicator and included in the study as species with sensitivity 3 by the SoSindex (see table 2). The correlation between the percentage of typical species and trawling effort was significant and negative (Spearman coefficient:  $Rho = -0.76$   $p\text{-val} < 0.001$ ), figure 13 shows the decreasing proportion of sentinel species with increasing trawling effort. There is a slight increase in medium and high-pressure levels with respect to low-pressure levels, but the proportion of sentinel species reach levels close to zero with very high-pressure values. Figure 13 also shows other frequent metrics used to measure trawling impacts, such as Total biomass, richness and Shannon index. In this case, a significant and downward trend was also clear between the indices and the trawling effort.

Table 15. Sentinel species composition for the IM habitat.

Sensitivity	SENTINEL SPECIES
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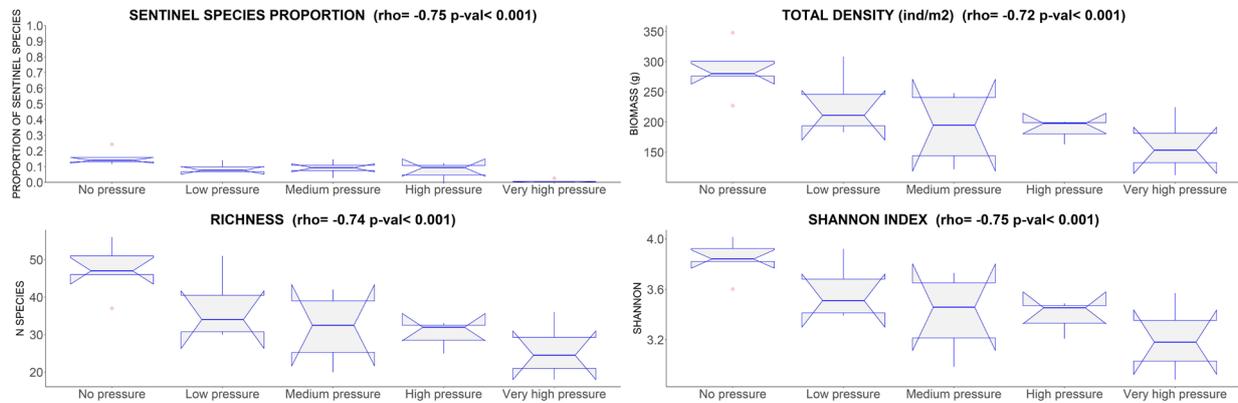


Figure 12. Proportion of sentinel species, Total abundance (biomass or density), Richness and Shannon index. Number of hauls per pressure level: No pressure=5, Low pressure=4, Medium pressure=4, High pressure=3, very high pressure=4.

### 5.3. Annex 3 –Application of SoS indicator to determine habitat environmental status; habitat sensitivity estimation and quality thresholds definition.

Once the predicted values of sentinel species proportion across the habitat were generated, they were classified into GES areas (or low disturbance areas) and no GES areas (moderate and high disturbance areas) by using a quality threshold specific for each habitat (minimum proportion of sentinel species acceptable to keep ecosystem processes).

To establish the quality threshold for each habitat was necessary to make three determinations based on the pressure-state curves of each habitat: Habitat sensitivity determination, degradation point calculation and quality threshold definition.

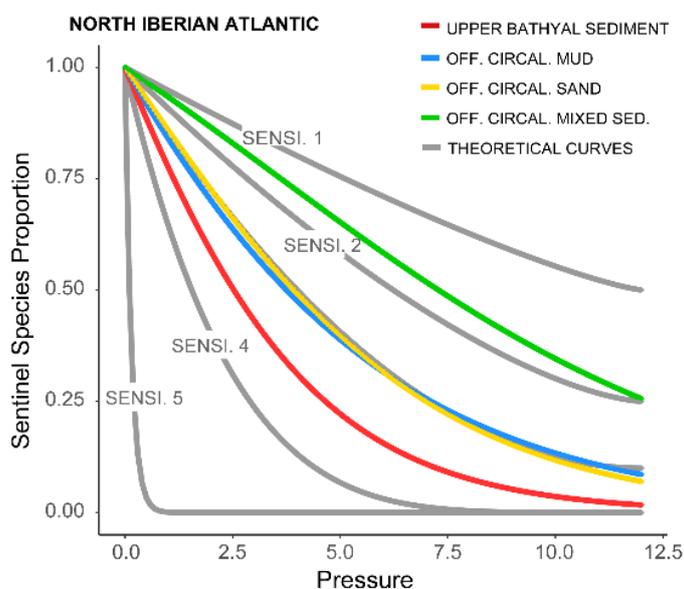
#### 5.3.1 Habitat sensitivity determination.

The threshold must be defined based on the specific sensitivity of the habitats to guarantee the habitat quality. The habitat sensitivity was calculated by comparing the response curve for each habitat with five theoretical models using an R function developed for this purpose (see <https://github.com/Gonzalez-Irusta/SoS>). The theoretical models were generated based on the pressure-state relationships described in Elliott et al. (2018), and they represent five different possible responses to pressure, from a sensitivity of 1 (no sensitivity) to 5 (very sensitive) (see figure 13). The function assigns a value from 1 to 5 to each habitat depending on the theoretical model which better fits the observed response of the SoS indicator to the pressure for that specific habitat (defined as the model with the lowest sum of squares of the difference between the real and each theoretical model). This calculation is repeated 1000 times using bootstrapping, obtaining the mean sensitivity of each habitat and its standard deviation based on the type of response observed in the SoS indicator (Table 16, Figure 13).

*Table 16. Habitat sensitivity for each North Iberian Atlantic MSFD Benthic BHTs analysed*

MSFD HABITAT	SENSITIVITY VALUE
OFFSHORE CIRCALITTORAL MIXED SEDIMENT	1.64 ± 0.5
OFFSHORE CIRCALITTORAL MUD	2.87 ± 0.38
OFFSHORE CIRCALITTORAL SAND	2.94 ± 0.23
UPPER BATHYAL SEDIMENT	3.60 ± 0.49

From this section to the end of the CEM guidelines, the SoS (BH1) methodology is applied to the data used in the BH1 assessment to carry out an inter-comparable regional approach to intercalibrate OSPAR indicators that will take place in the following annex. Therefore, here the curves (Figure 13) for each evaluated habitat obtained by applying the BH1 Assessment data are presented and used (Table 16).



*Figure 13. Theoretical (grey lines) and real (colour lines) pressure state curves by North-Iberian Atlantic assessment unit*

The upper bathyal sediment of the North Iberian assessment unit showed the most sensitive response, with a sharp decrease in the proportion of sentinel species at the first pressure values (Figure 13), a feature of the theoretical models for highly sensitive habitats (sensitivity 4; Table 16). Offshore circalittoral mud and offshore circalittoral sand habitats showed a pressure-state curve linked to the theoretical model for sensitive habitats (sensitivity higher than 3; Table 16), showing a quasi-linear response to pressure. However, a slope also affects their sensitivity (Figure 13). Finally, offshore circalittoral mixed sediments habitat showed a less sensitive pressure state curve (sensitive 2).

### 5.3.2 Degradation point calculation

The method consists of identifying the point at which the habitat has lost most of its quality (degradation point) and establishing the quality thresholds at different distances to this point depending on its sensitivity, giving the most sensitive habitats the highest distance to degradation. The degradation point is the point at which the pressure-state curves change their trend, decreasing the rhythm at which the reduction in the habitat state is observed. Although several statistical tools are being explored to obtain this point (Figure 14), currently, the method relies on the 45 degrees slope of the tangent to the curve, previously used in different works to determine the tipping point in aggregation curves (Colloca et al., 2009; González-Irusta & Wright, 2017)

### 5.3.3. Quality thresholds definition

Once this point has been computed, the condition threshold is established as a percentile of the distance between the origin of the curve and the degradation point (Figure 14). The thresholds generated must respond to the range of sensitivities of the different habitats, so a more conservative one will be used for sensitive responses, while a more permissive one will be applied for habitats with more tolerance to the pressure. For that, three thresholds were defined: (i) the standard which corresponds with the middle point between the beginning of the curve and the tipping point (p.50), (ii) the precautionary located in the first third of that range (p.33) and (iii) the tolerant threshold (p.66).

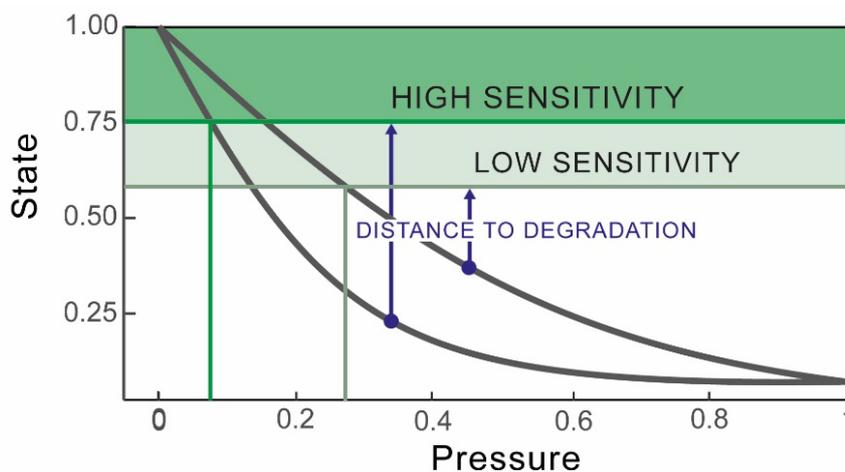


Figure 14. SoS methodology for setting quality thresholds to evaluate disturbance on benthic BHTs. The green lines show the quality threshold at different distances from the degradation point depending on the BHT's sensitivity.

SoS indicator used the precautionary threshold for habitats with a sensitivity value of 4, the standard for habitats with a sensitivity of 3 and the tolerant for habitats with a sensitivity of 2. The criteria that support the SoS methodology for setting quality thresholds are the most appropriate to date, but it is temporary. It may be modified in the future by expert agreements related to criteria to define the suitability of threshold values.

## 5.4. Annex 4 –BH1 and BH3 calibration. A pilot study in the North Iberian Atlantic assessment unit

### 5.4.1. Background

Indicators are key tools for assessing good environmental status for benthic/marine ecosystems and managing anthropogenic activities under the EU Marine Strategy Framework Directive (MSFD) and to support the implementation of the North East Atlantic Environment Strategy objectives related to benthic habitats. However, the lack of coherence between different indicators assessments at the E.U. member states' level could be a barrier to implementing the Directive. To address this issue, OSPAR has developed inter-comparable regionally harmonised approaches to monitor and assess the bottom integrity by developing six indicators (three are already common, one is a candidate, and two are under development). Despite this range of indicators, until now, OSPAR assessments concerning trawling impact have relied only on one indicator, the risk indicator BH3, because of the delay in developing other indicators. Consequently, BH3, specifically the BH3 disturbance matrix, was developed prior to the availability of quality-based indicators that could improve methods for calculating disturbance.

Following the Elliot *et al.* (2018) general scheme for the integration of OSPAR indicators for benthic habitats, the integration of BH1 (also called Sentinel of the Seabed, SoS, Serrano et al., 2022) and BH3 is here proposed to assess the state of benthic habitats in response to bottom trawling and applied as a pilot study in the North Iberian Atlantic assessment unit. The BH1 indicator is a quality indicator that measures the proportion of sentinel species within each MSFD benthic broad habitat as a proxy for its environmental status. It requires detailed monitoring data across the pressure gradient of each habitat assessed to determine the environmental status based on the pressure-state curves. On the other hand, the BH3 indicator is a risk assessment indicator, which establishes the overall impact on each habitat based on a disturbance matrix. It allows the evaluation of large marine areas even when only limited data is currently available by extrapolating data and knowledge from local studies. We propose a complementary evaluation based on the BH3-BH1 tandem to reduce uncertainties and spatial gaps. Specifically, this study uses the BH1 pressure-state curves to feed the BH3 disturbance matrix, providing habitat quality status data to define the fishing pressure scale and the matrix underpinning disturbance categories of BH3. In this way, regional data derived from the BH1 indicator are used to inform the BH3 matrix, providing a solid basis for assumptions underpinning the BH3 method. Although the method proposed here uses the BH1, other pressure indicators (such as BH2b, another OSPAR Indicator to determine the status of benthic habitats based on the Margalef diversity) could be used similarly and complementary to provide a broader range of evidence.

### 5.4.2. Methods for the comparison between the BH1 and BH3 assessments

#### 5.4.2.1 Indicators

BH1 and BH3 are indicators developed to determine the condition of Benthic Broad Habitat Types (BHTs) in response to a physical disturbance, fishing bottom trawling, and are primarily linked to D6C3 (although they also can play a role in D6C5). BH3 is a risk-based indicator, whereas BH1 is mainly a quality indicator which can be used as a risk-based indicator under certain circumstances.

#### 5.4.2.1.1 Benthic sensitivity

BH3 indicators use an underlying data layer that describes benthic sensitivity ranging from 1 to 5, with the highest score being the most sensitive. On the other hand, the BH1 does not use a sensitivity layer but provides a method to score benthic BHTs sensitivity based on the pressure-state curve statistically fitted for each habitat using General Additive Models (GAMs).

##### (i) BH1

Within the BH1 methodology, the sensitivity is estimated from the pressure-state curve fitted to each benthic BHTs and pressure, and it is specific to that pressure (in this case, trawling) and habitat. The pressure-state curve is compared with five theoretical sensitivity curves (i.e. five theoretical curves on how the state can change with pressure), and the most similar is selected. The highest score is the most sensitive (see annex III for more information on the method).

##### (ii) BH3

The sensitivity is determined per biotopes, ranging from Level 4 to 6 of the EUNIS classification, and calculated as a combination of the different sensitivity scores weighted by the habitat area with that score (BH3 composite habitat map) and is estimated to any seafloor abrasion, including surface and subsurface abrasion by trawling and sediment extraction (for more information see BH3 CEMP OSPAR, 2022).

#### 5.4.2.1.2 Risk-based benthic impact

##### (i) BH1

The prediction of the benthic BHTs impact is estimated as the variation of the prediction of sentinel species proportion by trawling across grid cells (lower values are habitats more at risk). The prediction is determined by the pressure-state curves specific for each benthic BHTs analysed based on sampled data (see annex II).

##### (ii) BH3

The impact of benthic BHTs is predicted from the disturbance matrix (Figure 15), which combines pressure categories and sensitivity of species and habitats. It covers all habitat types, including fine-scale biotopes and BHTs. The matrix was created based on Schroeder et al. (2008) pressure-state curves and refining using expert judgment (BH3 CEMP OSPAR, 2022).

Disturbance matrix		Sensitivity				
		1	2	3	4	5
Pressure	0 - ≤0.33	1	2	3	4	6
	>0.33-≤0.66	1	2	4	6	7
	>0.66-≤1	1	3	5	7	9
	>1.00-≤3	1	4	6	8	9
	>3	2	4	7	9	9

Figure 15. BH3 disturbance matrix (BH3 CEMP OSPAR, 2022)

### 5.4.2.1.3 Risk-based benthic level of disturbance

Both indicators recognize their thresholds are under development, pending agreed-upon criteria to define the suitability of quality threshold values. However, there is a definition of temporary thresholds in both assessments since the prediction of benthic impact is presented into three disturbance categories; if there are categories, there are thresholds (or boundaries) that define them. This categorisation was agreed to be able to inter-compare the bottom integrity assessments concerning trawling impact (BH3 and BH1) for the QSR 2023 until how to categorise the habitat status is agreed.

#### (i) BH1

Once the predicted values of sentinel species proportion across the habitat were generated, they were converted into high disturbance, moderate disturbance, low disturbance and no pressure areas by using a quality threshold specific for each BHT (minimum proportion of sentinel species acceptable to keep ecosystem processes). These categories were established instead of GES or no GES because of current lack of agreement on quality thresholds. However, a method to compute these values has been developed as part of BH1 methodology (annex III) and it was preliminary applied here to define 4 categories: (i) no pressure, the value of the pressure on the area is zero, (ii) low disturbance when the proportion of sentinel species was higher than the quality threshold, even after removing the standard error; (iii) high disturbance when the proportion of sentinel species was minor than the quality threshold, even after adding the standard error and (iv) moderate disturbance areas when the position (higher or lower) of the proportion of sentinel species related to the quality threshold changes after adding/removing the standard error.

#### (ii) BH3

The resulting disturbance categories (Figure 16) are summarised into four groups ('Zero' = disturbance category 0, 'Low' = disturbance categories 1-4, 'Moderate' = disturbance categories 5-7, and 'High' = disturbance categories 8 and 9). These categories differ from those presented in 2021 when there were only two (low disturbance from 1-4 or high disturbance from 5-9). These groupings are currently used to compare disturbance outputs across the OSPAR Maritime Area.

Disturbance matrix		Sensitivity				
		1	2	3	4	5
Pressure	1	1	2	3	4	6
	2	1	2	4	6	7
	3	1	3	5	7	9
	4	1	4	6	8	9
	5	2	4	7	9	9

Figure 16. BH3 disturbance matrix with the disturbance levels established by thresholds.

### 4.2.2 Common data set

The impacts on the seafloor associated with the bottom-contacting fishing activity are considered the most widespread disturbances in the North Atlantic Iberian assessment unit. Therefore, it was expected that the effects of trawling on benthic communities would have a more significant impact than any differences in the environmental conditions. VMS layers analysed were derived from the total aggregated VMS layers from 2009 to 2020, prepared by ICES for an OSPAR request within the

OSPAR Maritime Area (ICES, 2021, Figure 17). At the difference of the data used for the BH1 assessment, data from ICES has not been modified to maximise comparability between indicators. The distribution of trawling effort (i.e. swept area ratio) map used to produce both assessments was generated based on the mean values of fishing effort across the assessment period (i.e. from 2009 to 2020 for QSR).

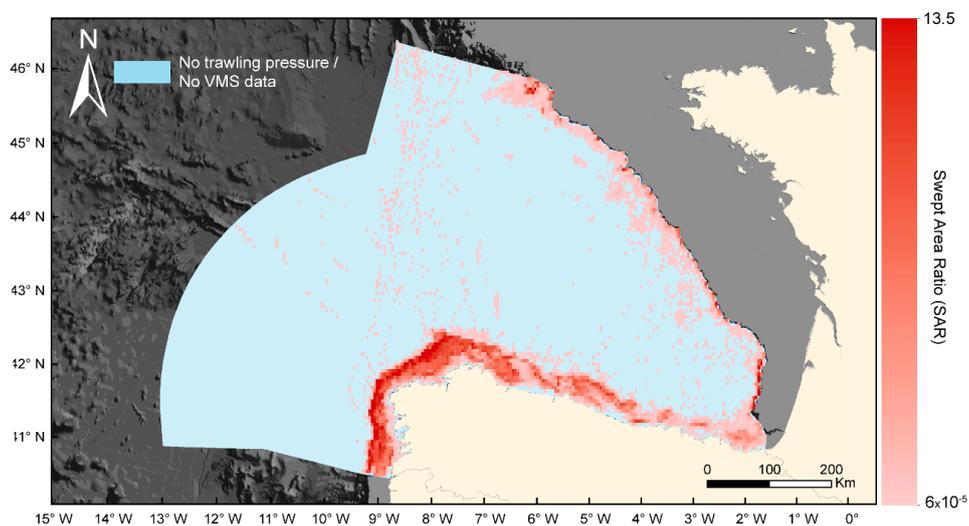


Figure 17. Mean swept area ratio (SAR) from 2009-2020 (top) from the North Iberian Atlantic assessment unit. VMS data is used to test the indicator's performance.

#### 5.4.3 Differences between current BH1 and BH3 results

BH1 and BH3 results by BHTs presented a general good agreement in its disturbance values as showed by the rho value obtained when both indicators were compared ( $r_{\text{spearman}} = -0.76$ ).

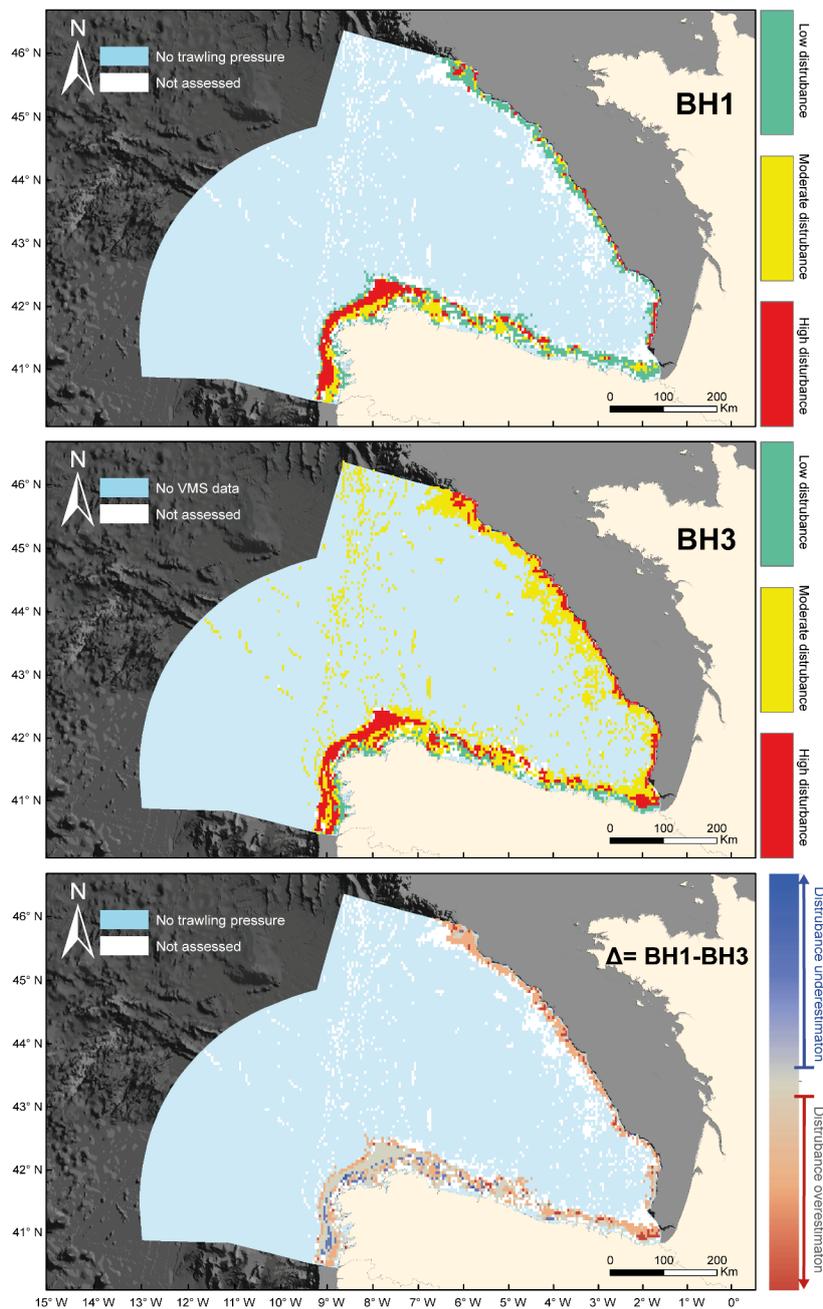


Figure 15. Risk-based benthic level of disturbance estimations determined by BH1 and BH3 indicators, and the differences between them, for the North Iberian Atlantic assessment unit.

When the analysis was performed per BHT, significant correlations were also found for some of the benthic BHTs analysed, although the variation was high between habitats (with some habitats also showing lower or even not significant correlations). However, with the inclusion of temporal threshold values, the non-linear correlation between both indicators appear more clear, generating important differences in the final outputs of both indicators, especially when the areas in low, moderate or high disturbance are compared (Figure 18). These differences justify the need to continue working on better integration of both indicators to remove (when possible) differences in the methodology of both indicators that can be responsible for these differences, using when available ground-truthing data to support this integration.

### 5.4.3.1. Defining pressure categories with ecological meaning

To advance in integrating both indicators and their comparability, the BH3 disturbance matrix must incorporate the best information available, using data from quality indicators such as BH1, which is already acknowledged in the last update of BH3 CEMP guidelines. For this reason, ecological pressure categories are proposed here, extracted from the pressure-state curves of the BH1, and therefore, specific for trawling, the region, and the different habitat sensitivities (Figure 19).

#### (i) Pressure category 1

Pressure category 1 determines the pressures at which habitats with a sensitivity of 4 are undisturbed. Therefore, this category will start at higher than Zero SAR values, and the final limit of this category will be defined by the quality threshold for habitats with a sensitivity of 4. Based on BH1 current outputs, this category encompasses SARs from 0 to 1, although the final values still need to be agreed.

#### (ii) Pressure category 2

Pressure category 2 determines the pressures in which habitats with a sensitivity of 4 are disturbed while habitats with a sensitivity of 3 are undisturbed. Therefore, this category will start at the quality threshold for habitats with a sensitivity of 4. The final limit of this category will be defined by the pressure from which the habitats with a sensitivity of 3 starts to be degraded (the quality threshold for habitats with a sensitivity of 3). Based on BH1 results, this category varies from 1 to 1.8 SARs values, although the final values still need to be agreed.

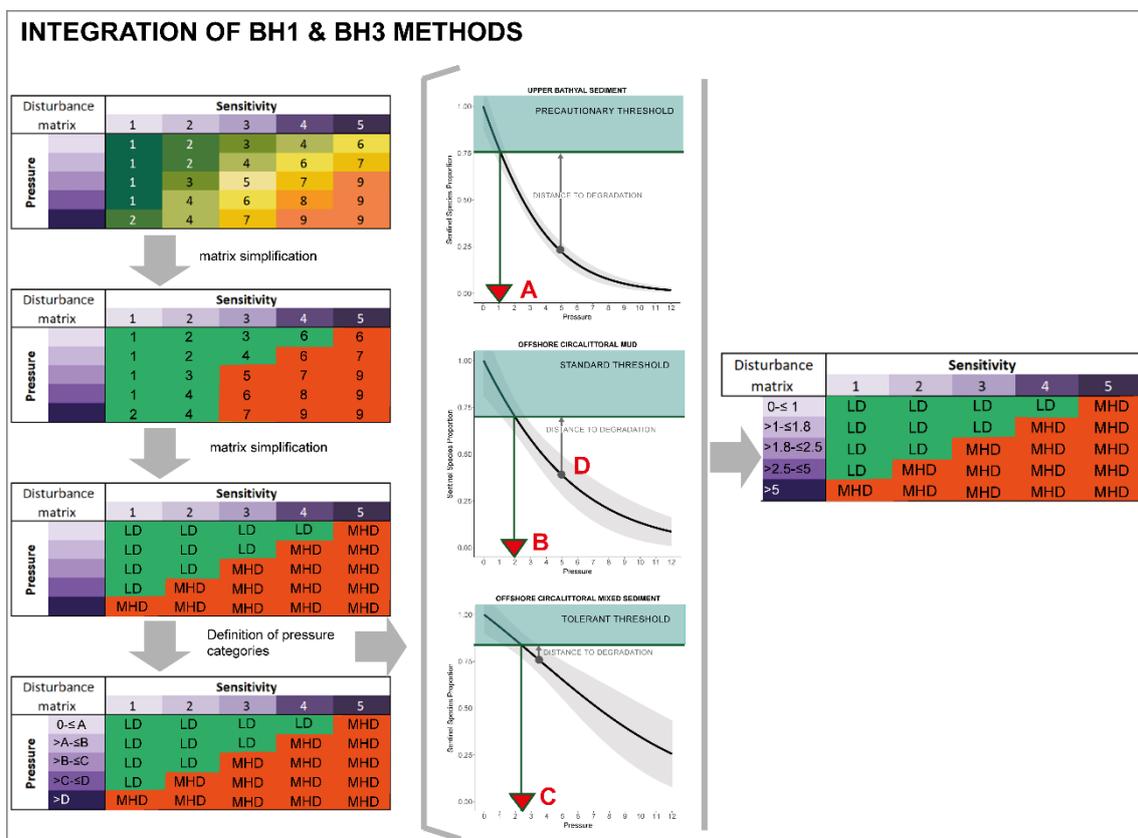


Figure 16. Scheme of the indicators methods integration that is proposed. LD: Low disturbance. MHD: Moderate/high disturbance

### (iii) Pressure category 3

Pressure category 3 determines the pressures in which habitats with a sensitivity of 3 are disturbed while habitats with a sensitivity of 2 are undisturbed. Therefore, this category will start at the quality threshold for habitats with a sensitivity of 3, and the final limit of this category will be defined by the quality threshold for habitats with a sensitivity of 2. Based on BH1 current outputs, this category encompasses SARs from 1.8 to 2.5, although the final values still need to be agreed.

### (iv) Pressure category 4

Pressure category 4 determines the pressures in which habitats with a sensitivity of 2 are disturbed while habitats with a sensitivity of 1 are undisturbed. Therefore, this category will start at the quality threshold for habitats with a sensitivity of 2, and the final limit of this category will be defined by the quality threshold for habitats with a sensitivity of 1. This category ranges from 2.5 to 5 SAR values, although the final values still need to be agreed.

### (v) Pressure category 5

Pressure category 5 determines the pressures under which all habitats, regardless of their sensitivity, are disturbed. This category will start at SAR values obtained for the point of degradation that showed the highest SAR of the habitats analysed by the BH1. Based on BH1 current outputs, this category picks up SAR values > 5, although the final values still need to be agreed.

## 5.4.4 Conclusions

This annex compared, in the frame of the following OSPAR quality status report of 2023 and for part of Region IV (North Iberian assessment unit), two benthic habitat indicators: BH1 (common in region IV) and BH3 (common in region II III and IV). Furthermore, this work proposed a method to combine both indicators in future assessments as a method of integration or to use BH1 curves to calibrate and improve BH3 disturbance values.

Despite obvious differences in the methods and philosophy of both indicators (BH3 is a risk indicator and BH1 is a quality indicator), there was certain consensus in their results, especially in terms of relative values, which has its reflection in the high level of correlation observed between the outputs of both indicators. This correlation is also high when the comparison is made habitat by habitat, although with a higher level of variation. Unfortunately, this high level of agreement disappears when the outputs of both models are used to determine the proportion of each habitat exposed to a low, moderate or high level of disturbance (so when the quality threshold starts to be applied). BH3 overestimates the disturbance level compared to BH1, determining that nearly 90% of the total extent of the studied area is exposed to moderate or high disturbance compared to the nearly 50% obtained when BH1 was used. BH3 categories for habitats with a sensitivity of 3 (0.66 SAR) or 4 (0.33 SAR) were lower than the thresholds determined using the BH1 methodology.

In order to help to reduce these differences (derived from the lack of inclusion of quality indicator inputs in the disturbance matrix), a method to inform the disturbance matrix with information from BH1 and other quality indicators is proposed in this pilot study. Our proposal is based on defining each quality category of the disturbance matrix according to its ecological meaning and using the values from the quality thresholds to define the boundaries when possible. To maximise BH3 utility, we think it is key that the pressure categories show a good agreement with the quality threshold defined for each benthic habitat. In this sense, although the numerical values suggested in this pilot

study for each category are not final of each category and may be modified once more data and indicators can be used to define quality thresholds, it is more crucial than the theoretical approach delineated by Elliot et al. (2018) and further developed in this study can be adopted for BH3.

## 6. References

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- Beiras R, Durán I, Parra S, Urrutia MB, Besada V, Bellas J, Viñas L, Sánchez-Marín P, González-Quijano A, Franco MA, Nieto O, González JJ. 2012. Linking chemical contamination to biological effects in coastal pollution monitoring. *Ecotoxicology*, 21: 9–17
- Bellas J, Nieto O, Beiras R. 2011. Integrative assessment of coastal pollution: development and evaluation of sediment quality criteria from chemical contamination and ecotoxicological data. *Continental Shelf Research*, 31: 448-456
- Borja A, Franco J, Pérez V. 2000. A Marine Biotic Index to Establish the ecological Quality of Soft-Bottom Benthos Within European Estuarine and coastal Environments. *Marine Pollution Bulletin*, 40, 12: 1100-1114
- Bremner J, Rogers SI, Frid CLJ, 2006. Matching biological traits to environmental conditions in marine benthic ecosystems. *Journal of Marine Systems* 60: 302–316.
- Buchanan JB, 1984. Sediment analysis. En: Holme, N.A. y McIntyre, A.D. (eds.) *Methods for the study of marine benthos*, Blackwell Scientific Publications, Oxford, 41-65
- Buhl-Mortensen L, Aure J, Our O, 2009. The response of hyperbenthos and infauna to hypoxia in fjords along the Skagerrak: estimating loss of biodiversity due to eutrophication. In: Monksness, E., Stotterup, E., Dahl, J. (Eds.), *Integrated Coastal Zone Management*. Wiley-Blackwell Publ, UK, pp.79-96.
- BOE, 2014. Orden AAA/2280/2014, de 1 de diciembre, por la que se aprueba la propuesta de inclusión en la lista de lugares de importancia comunitaria de la Red Natura 2000 de los espacios marinos ESZZ12003 Sistema de Cañones Submarinos de Avilés, ESZZ16003 Sur de Almería-Seco de los Olivos, ESZZ16005 Espacio Marino de Alborán, ESZZ16004 Espacio Marino de Illes Columbretes y ESZZ15001 Banco de la Concepción.
- Dauvin JC, 2007. Paradox of estuarine quality: benthic indicators and indices, consensus or debate for the future. *Marine Pollution Bulletin*, 55: 271-281.
- De la Torriente A, Aguilar R, Serrano A, García S, Fernández LM, García Muñoz M, Punzón A, Arcos JM, Sagarminaga R, 2014. *Sur de Almería- Seco de los Olivos*. Proyecto LIFE+INDEMARES. Ed. Fundación Biodiversidad del Ministerio de Agricultura, Alimentación y Medio Ambiente. 102 pp.
- De Juan S, Demestre M, 2012. A Trawl Disturbance Indicator to quantify large scale fishing impact on benthic ecosystems. *Ecological Indicators* 18, 183-190.
- Elliott, S. A., Guérin, L., Pesch, R., Schmitt, P., Meakins, B., Vina-Herbon, C., Serrano, A., 2018. Integrating benthic habitat indicators: working towards an ecosystem approach. *Marine Policy* 90, 88-94.
- EMODnet, 2021. Seabed Habitats. Available at: <https://emodnet.ec.europa.eu/en/seabed-habitats>.
- EU, 1992. Habitat Directive 92/43/EEC, Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

- EU, 2006. No. 1967/2006 of 21 December 2006, concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, amending Regulation (EEC) No. 2847/93 and repealing Regulation (EC) No. 1626/94. Official Journal of the European Union.
- EU, 2008. Marine Strategy Framework Directive (DIRECTIVE 2008/56/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 June 2008 establishing a framework for community action in the field of marine environmental policy). Official Journal of the European Union.
- Freeman EA, Moisen GG, 2008. A comparison of the performance of threshold criteria for binary classification in terms of predicted prevalence and kappa. *EcologicalModelling* 217: 48–58 doi:10.1016/j.ecolmodel.2008.05.015.
- González-Irusta JM, Punzón A, Serrano A, 2012. Environmental and fisheries effects on *Gracilechinus acutus* (Echinodermata: Echinoidea) distribution: is it a suitable bioindicator of trawling disturbance? *ICES Journal of Marine Science*, 69, 1457-1465.
- Grall J, Glemarec M, 1997. Using biotic indices to estimate macrobenthic community perturbations in the Bay of Brest. *Estuarine, Coastal and Shelf Science* 44 (suppl. A), 43±53.
- Greene HG, Bizzarro JJ, Tilden JE, Lopez HL, Erdey MD, 2005. The benefits and pitfalls of geographic information systems in marine benthic habitat mapping. In: D.J. Wright and A.J. Scholz (eds.), *Place matters*. Oregon State University Press, Portland, pp. 34-46.
- Hering D, Feld CK, Moog O, Ofenbock T, 2006. Cook book for the development of Multimetric Index for biological condition of aquatic ecosystems : experiences from the European AQEM and STAR projects and related initiatives. *Hydrobiologia* 566, 311- 324.
- Hily C, 1984. *Variabilité de la macrofaune benthique dans les milieux hypertrophiques de la Rade de Brest*. These de Doctorat d'Etat, Univ. Bretagne Occidentale. Vol. 1, 359 pp; Vol. 2, 337 pp.
- Hintzen, N. T., Piet, G. J., and Brunel, T. 2010. Improved estimation of trawling tracks using cubic Hermite spline interpolation of position registration data. *Fisheries Research*, 101: 108–115.
- ICES, 2015. Interim Report of the Working Group on Marine Habitat Mapping (WGMHM), 18–22 May 2015, Reykjavik, Iceland. ICES CM 2015/SSGEPI:12. 31 pp.
- ICES, 2021. OSPAR request on the production of spatial data layers of fishing intensity/pressure. ICES Advice 2021.
- Jiménez-Valverde A, Lobo JM, 2007. Threshold criteria for conversion of probability of species presence to either–or presence–absence. *Acta Oecologica*, 3, 3: 361-369.
- Jones CG, Lawton JH, Shachak, M, 1994. Organisms as ecosystem engineers. *Oikos* 69: 373–386. doi: 10.2307/3545850.
- Jones CG, Lawton JH, Shachak M., 1997. Positive and negative effects of organisms as physical ecosystem engineers. *Ecology* 78: 1946-1957
- Kaiser M, Spencer B, 1995. Survival of by-catch from a beam trawl. *Mar. Ecol. Prog. Ser.*, 126, 31-38.

- Koslow JA, Boehlert GW, Gordon JDM, Haedrich RL, Lorance P, Parin N, 2000. Continental slope and deep-sea fisheries: implications for a fragile ecosystem. *ICES Journal Marine Science.*, 57, 548-557
- Liu C, Berry P, Dawson T, Pearson R, 2005. Selecting thresholds of occurrence in the prediction of species distributions. *Ecography* 28, 385–393.
- MAGRAMA, 2012. Estrategia Marina para la Demarcación Marina Noratlántica, Parte IV. Descriptores Del Buen Estado Ambiental, Descriptor 1: Biodiversidad, Evaluación Inicial Y Buen Estado Ambiental. [http://publicacionesoficiales.boe.es/NIPO: 280-12-175-8](http://publicacionesoficiales.boe.es/NIPO:280-12-175-8).
- OSPAR Commission, 2017. OSPAR Coordinated Environmental Monitoring Programme (CEMP) Guidelines. Common Indicator: BH3 Extent of Physical damage to predominant and special habitats (<https://www.ospar.org/documents?v=37641>).
- Punzón, A., Arronte, J. C., Sánchez, F., and García-Alegre, A. 2016. Spatial characterisation of the fisheries in the Avile' 's Canyon System (Cantabrian Sea, Spain). *Ciencias Marinas*, 42: 237–260.
- Queirós A, Hiddink J, Kaiser M, Hinz H, 2006. Effects of chronic bottom trawling disturbance on benthic biomass, production and size spectra in different habitats. *Journal of Experimental Marine Biology and Ecology*, 335, 91-103.
- Samhuri, J. F., Levin, P. S., & Ainsworth, C. H. 2010. Identifying thresholds for ecosystem-based management. *PLoS One*, 5(1), e8907.
- Sánchez F, Serrano A, 2003. Variability of groundfish communities of the Cantabrian Sea during the 1990s. *ICES Marine Science Symposia*, 219, 249-260.
- Serrano A, Sánchez F, Punzón A, Velasco F, Olaso I, 2011. Deep sea megafaunal assemblages off the northern Iberian slope related to environmental factors. *Sci. Mar.*, 75 (3), 425-437.
- 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.
- Tagliapietra D, Sigovini M, Ghirardini AV, 2009. A review of terms and definitions to categorise estuaries, lagoons and associated environments. *Marine and Freshwater Research* 60, 497-509.
- Van Denderen PD, Bolam SG, Hiddink JG, Jennings S, Kenny A, Rijnsdorp AD, van Kooten T, 2015. Similar effects of bottom trawling and natural disturbance on composition and function of benthic communities across habitats. *Marine Ecology Progress Series*, 541, 31-43.