Spatial assessment of benthic habitats vulnerability to bottom fishing in a Mediterranean seamount

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ABSTRACT

Physical damage caused by the mechanical impact of bottom fishing gears on epibenthic community can reduce the biomass and coverage of habitat-forming species as well as the richness and diversity of the rest of the associated community. A practical development of a methodology for spatially assessing the potential degree of disturbance that benthic habitats suffered as a consequence of trawling and long-lining was carried out using a seamount located within a marine Natura 2000 site in the western Mediterranean as a case of study. By jointly assessing the extent of the impact and mapping the sensitivity of all the habitats to these fishing activities, vulnerability and disturbance per benthic habitat and pressure type was evaluated. Habitat sensitivity and fishing effort were combined using a disturbance matrix which categorize grid cells in 9 different levels of disturbance. Additionally, different thresholds of probability of presence of the different habitats obtained from distribution models were used to identify priority conservation and potential recovery. Around 50% of the area was disturbed by fishing and all habitats, both biogenic and non-biogenic, were subjected to fishing. Most of the trawling effort was carried out on soft bathyal substrates while the percentage of longlining effort carried out on hard bottoms was relatively higher than for trawling. Biogenic habitats showed significantly greater sensitivity to both trawling and longlining than non-biogenic habitats. Disturbed, priority conservation and potential recovery areas were identified and mapped in order to inform marine spatial planning.

1. Introduction

Deep-water fishing activities have negative impacts on benthic habitats in all oceans worldwide [123,164]. In addition to the direct extraction of target and non-target species, the physical damage caused by the mechanical impact of fishing gears on epibenthic community can reduce the biomass and coverage of habitat-forming species as well as the richness and diversity of the rest of the associated community [34, 61,70,83,120]. All this leads to shifts in community composition and habitat structure and, ultimately, to changes in the ecosystem functioning [2,78,139,159].

Biodiversity protection and conservation of complex ecological interactions of natural ecosystems is needed to ensure the maintenance of ecosystem services for the future society (Duarte and Moreno, 2000; [85, 167]). Among these services, sustainable fisheries require viable stock populations but also healthy habitats, which provide feeding, protection and reproduction places for commercial fish and invertebrate species

[120]. A strategy based on ecosystem-based fishery management (EBFM) was adopted by the current European Union Common Fishery Policy (CFP) for fishery management with the overall objective of sustaining healthy marine ecosystems and the fisheries they support [6111, 135]. As part of the implementation of this ecosystem approach, international and European regulations such as the Habitat Directive (HD, 1992/43/CEE,) and the Marine Strategy Framework Directive (MSFD, 2008/56/EC) have encouraged the creation of coherent and connected Marine Protected Areas (MPAs) networks, focused on achieving a balance between sustainable fisheries and other human activities, and habitats conservation.

However, to be truly effective in achieving the conservation and management objectives for which they were created, MPAs require management strategies that consider various spatial scenarios and that integrate both concepts of biodiversity protection – including the potential recovery and restoration of degraded habitats – and the sustainable use [148]. The marine scientific community has made great

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progress in the characterization of the benthic communities and the distribution of Vulnerable Marine Ecosystems (VMEs, e.g. [26,45,64, 125,143,155,163]) as well as in the identification of the main human threats that potentially impact on marine biodiversity [42,51,69,133] and the detection of long-term changes in benthic communities as consequence of trawling and long-line fishing disturbance [3116,152]. However, despite advances in research on habitats and threats, there are still challenges in these data integration with the aim of quantifying the extent of the damage under different possible management scenarios, which is currently a primary concern for governments.

Methodologies and indicators to detect physical damage caused by human activities are being tested in the framework of international conventions such as the International Council for the Exploration of the Sea-ICES, OSPAR and Barcelona Convention, with the aim of guiding spatial management and implement preventive as well as mitigating measures suitable to be used in the scope of HD, MSFD and CFP. Particularly, related to descriptor 6 "Sea-floor integrity", several OSPAR indicators (e.g. Typical species composition-BH1 and Extent of Physical Damage to Predominant and Special Habitats-BH3; [52]) and the Mediterranean indicator "Habitat range", face this challenge. Besides, Elliot et al., (2018) suggested a methodology that will eventually provide disturbance maps to serve managers, based on the integration of habitat sensitivity maps and the distribution of the intensity of the pressure within the area of study. These two datasets are combined using a disturbance matrix to obtain a disturbance map per benthic habitat and pressure type.

In order to assess the sensitivity of benthic communities to fishing activities, since not all habitats are equally sensitive to them [37,69], there has been much progress in recent years by using Biological Traits Analysis (BTAs) (e.g. [40,42,69,84,121,160,162]). Habitats subjected to high levels of natural disturbance are more resilient than structurally complex biogenic habitats which usually are relatively undisturbed by natural perturbations [37,82,162]. In the same line, healthy biogenic habitats composed of long-lived species with higher functional redundancy are more susceptible to physical disturbance than degraded habitats [46,48,126], which is reflected by their own characteristics, biological and functional traits [17,69]. Therefore, the ecological responses of benthic habitats to fishing disturbance are the result of combining the sensitivity of a set of key species that is part of each habitat or of the total set of species that make up each habitat [116], which have associated intra- and interspecific relationships among them within the habitats [42,69].

The Seco de los Olivos is a seamount with high ecological importance and biodiversity value located within a Site of Community Importance (SCI) of the Natura 2000 network, which requires a management plan to become Special Areas of Conservation (SAC). As a result of the LIFE+ INDEMARES project, a wide range of vulnerable marine ecosystems with a patchy distribution has been characterized such as mixed cold-water corals, gorgonians and black corals gardens, sponge aggregations, sea pen fields and giant oyster facies on hard bottoms as well as sea pens and bamboo corals fields on soft bottoms [47]. However, the area is frequented by both professional and recreational fishermen who use different fishing gears such as otter trawls, gillnets, trammel nets, long-lines and pots [43], which act over different types of substrates and potentially modify the integrity of benthic communities.

In this study, using this seamount as a case of study, we carried out a practical development of the specific methodology proposed by Elliot et al. (2018) to evaluate the distribution of the different degree of disturbance that benthic habitats suffered as a consequence of industrial bottom trawling and long-line fishing -described as the major pressures in the area-. We forecasted the distribution of the potential influence that may have fishing activities on the benthic habitats, by jointly spatially assessing the extent of the impact and mapping the sensitivity of all the habitats to these activities. In addition, we used different thresholds of probability of presence of the different habitats obtained from distribution models to define both, priority conservation and

potential recovery areas. Since restoration concepts are unachievable in the short term (Van Dover et al., 2014), spatial management has been recognized likely to be the most effective strategy to conserve benthic communities of seamount ecosystems [36,154] offering also an opportunity to improve our understanding of recovery for future management.

All of this information -disturbed, priority conservation and potential recovery areas-, taken together, could be used to inform marine spatial planning and ecosystem-based management in this MPA.

2. Materials and methods

2.1. Study Area

The Seco de los Olivos Seamount is a marine biodiversity hotspot [43,44,113] located within the SCI "Sur de Almería-Seco de los Olivos" (Orden AAA/2280/2014) of the Natura 2000 network, designated to ensure the protection of specific species (*Caretta caretta* and *Tursiops truncatus*) and habitats (1120-*Posidonia oceanica* meadows and habitat 1170- Reefs). Also known as Chella Bank (e.g. [4112]), is a completely submerged volcanic feature located approximately 10 nautical miles off the Southern coast of Spain, in the Northeast Alboran Sea, Western Mediterranean (Fig. 1).

It covers a total area of about 100 square kilometers, with a depth range between 70 and 700 m. A variety of habitat-forming species that appear in high densities in this small area, conforming what is known as "marine animal forests" [60,149] has been recorded [44,45]. This biodiversity hotspot is also a valuable fishing area for professional and recreational fishermen, probably due to the high availability of food caused by local currents and upwellings that enhance primary production and plankton biomass in the area [1]. A wide variety of fishing techniques are used in this seamount including those demersal fisheries which brings fisheries into direct contact with benthic habitats and species, such as otter trawl catching blue whiting (*Micromesistius poutassou*), blackbelly rosefish (*Helicolenus dactylopterus*), silvery pout (*Gadiculus argenteus*) and hake (*Merluccius merluccius*) [1]; set gillnet used for *Pagellus* spp., blue whiting, red scorpionfish (*Scorpaena* spp.) and mullets (*Mullus* spp.); traps used for soldier shrimp (*Plesionika* spp.); and set bottom long-line targeting blackspot seabream (*Pagellus bogaraveo*) [8]. Because of their proximity to the Spanish coast, recreational fishing has also reached a very important level in Seco de los Olivos, mostly on the steeper slopes of the surrounding ridges, where species coveted by this fishing are found, such as the grey grouper (*Epinephelus caninus)* [43].

The spatial assessment carried out in this study can be of help to inform the management plan required in this area to become a SAC of the Natura 2000 network.

2.2. Benthic Habitats data

Eight biogenic benthic habitats were identified and modeled in previous studies [44,45] (Table 1; Fig. Supplementary 1), all of them characterized by epibenthic megafaunal species. An additional habitat structured by *Caryophyllia smithii* (var. *clavus)* on sandy bottoms was identified in those works but it was excluded from this study because we reckoned that it did not create a structural complexity that would support a community that would be modified by physical damage from bottom fishing. Additionally, in the framework of this study, five distinct non- biogenic benthic habitat types (not structured by some epibenthic megafaunal species) were identified and their distribution modeled by combining layers of seabed type and bathymetry. Mud and detritic sand were grouped together into "soft bottoms" while dead coral framework and rock were grouped into "hard bottoms"(Table 1).

Biogenic habitat distributions were obtained in the previous study by selecting as presence value, for each pixel, only those predicted probabilities of presence higher than their prevalence [45]. To obtain a complete single continuous raster map of all benthic habitats, both
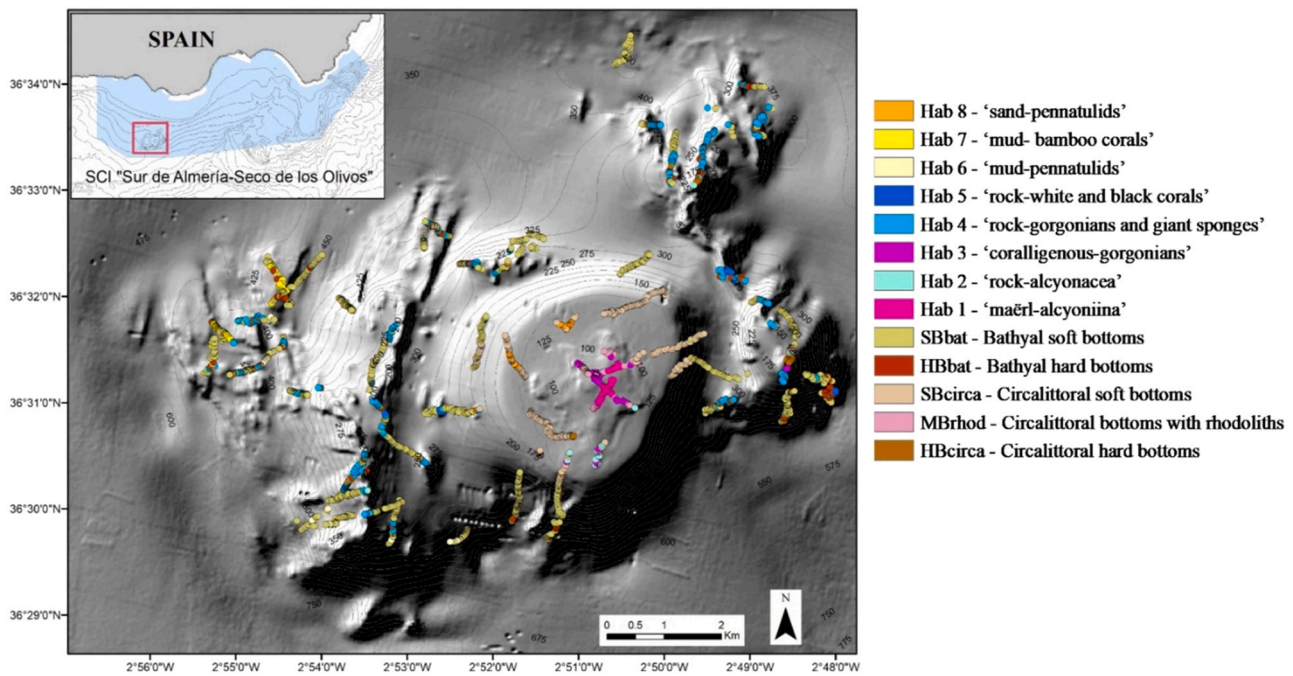
Fig. 1. Map of the Seco de los Olivos Seamount showing the Remotely operated vehicle (ROV) sampling stations (color dots) recorded across the seamount. Biogenic benthic habitats identified and mapped in previous studies [44,45] are displayed in different colors. The inset shows the location of the seamount (red square) close to the south-west edge of the SCI "Sur de Almería- Seco de los Olivos" (blue polygon) and within the Mediterranean Sea.

Table 1

Main benthic habitats (biogenic and non-biogenic) identified and modeled at the Seco de los Olivos seamount. The names in quotation marks indicate the short name of the habitats used throughout the text and figures.

BENTHIC HABITAT	NAME
BIOGENIC HABITATS	
1	Circalittoral maërl or rodholites with *Alcyonium palmatum* and *Paralcyonium spinulosum* ('maërl-alcyoniina')
2	Circalittoral rock with *Viminella flagellum* and *Chironephthya mediterranea* ('rock-alcyonacea')
3	Circalittoral rock with *Eunicella verrucosa* and *Paramuricea clavata* ('coralligenous-gorgonians')
4	Bathyal hard substrate with gorgonians (*Acanthogorgia hirsuta* and *Swiftia pallida*) and sponges (*Asconema setubalense* and other white sponges) ('rock-gorgonians and giant sponges')
5	Bathyal hard substrate with corals (*Madrepora oculata*, *Savalia savaglia* and *Leiopathes glaberrima*) ('rock-white and black corals')
6	Bathyal mud with pennatulids (*Kophobelemnon stelliferum*) ('mud-pennatulids')
7	Bathyal mud with *Isidella elongata* ('mud- bamboo corals')
8	Circalittoral detritic sand with pennatulids (*Pennatula rubra*) ('sand-pennatulids')
NON-BIOGENIC HABITATS	
SBcirca	Circalittoral soft bottoms
SBbat	Bathyal soft bottoms
MBrhod	Circalittoral bottoms with rhodoliths
HBcirca	Circalittoral hard bottoms
HBbat	Bathyal hard bottoms

biogenic and non-biogenic habitats were merged, keeping for each grid cell biogenic habitats when present, and only keeping non-biogenic habitats when no biogenic habitat was present. In each pixel where several biogenic habitats overlapped, the one with the highest probability of occurrence was selected.

2.3. Habitat sensitivity

Habitat sensitivity assessment was carried out by combining

resistance – ability of a system to remain unchanged despite disturbances [72] – and *recovery* – re-colonization or re-growth following disturbance, ideally towards pre-disturbance levels [115] – characteristics of species considering two specific pressures: trawling and long-line fishing. The sensitivity of each benthic habitat to each fishing pressure was calculated as a combination of the sensitivity of all the epibenthic megafaunal species making up the biological component of each habitat. We also calculated the sensitivity using only the habitat-forming species (HFS) or using only the most sensitive species in each habitat, since some authors have proposed that habitats sensitivity should be defined considering only key species (structuring and/or indicator species) whose loss from the community would be expected to seriously change the nature of the habitat and possibly its viability [116] rather than all the species present in the habitats. However, these analyses were discarded as they gave very similar results in all the non-biogenic habitats and were therefore less conclusive (Supplementary Table 3).

To perform this sensitivity assessments, species data from each benthic habitat were obtained from three ROV (Seaeye Falcon & Falcon DR) surveys conducted by OCEANA on board the Oceana Ranger from 2010 to 2012. Fifty-five ROV video transects of both soft and hard bottoms were analysed, covering approximately 67.52 km of benthic imagery scattered around the seamount (see details in [44,45]).

The sampling unit consisted of 1-min continuous movement ROV tracks within a single habitat at a 0.2–0.4 knot speed and thus, all megabenthic (> 2 cm) invertebrate falling into one sample were recorded, identified to the lowest possible taxonomic level and quantified in abundance terms (number of individuals or colonies). Samples with HFS in abundance of more than 5 individuals were associated with a specific biogenic habitat based on a cluster analysis made in a previous study [44]. This threshold was based on a curve of mean species richness obtained as a function of the number of HFS (not shown, see in [44]). In this curve a marked change in species richness occurred at abundances of five HFS individuals or colonies. This novel methodology for defining habitats based on species richness has also been more recently used in Rowden et al. [150]. The rest of samples, with less than five HFS individuals or colonies per sample, were classified as belonging to

non-biogenic habitats, based on their type of substrate (mud, detritic sand, maërl-rhodoliths, dead coral framework, and rock) and depth (circalittoral: <200 or bathyal: ≥200 m). For more details about sampling design, see [44].

Each species was assigned a sensitivity value for each fishing pressure using Biological Traits Analysis (BTA) and therefore, combining structural data for species communities with information related to the functional features of each species [23]. Nine biological traits were recorded: maximum size, longevity, motility, attachment, benthic position, flexibility, fragility, feeding mode and body form. Each trait was scored to classify each epibenthic megafaunal morphotype according to its association with different modalities of functional traits. Thus, each species or morphotype was assigned a value for each characteristic according to the modalities described in Table 2. Information on the characteristics or functional traits of each species was gathered from specific online data bases [117,168], scientific articles and grey literature and from expert judgement (when no other relevant information source was available, information was inferred from closely related species or higher taxa). The list of species and traits are provided in De la Torriente et al. [46].

In order to calculate the sensitivity of species to trawling, we used the BESITO index [69], which classifies species according to their response to trawling disturbance. This index assigns values ranged from 1 (lowest sensitivity) to 5 (highest sensitivity) to each species (Supplementary Table 2) by combining 8 biological traits (maximum size, longevity, motility, attachment, benthic position, feeding mode, flexibility and fragility) which reflects both resistance and recovery capacities of the species. The most sensitive species (group 5) were those sessile species, permanently attached, emergent (> 20 cm), long-lived species (>11 years) with medium or large sizes (>11 cm), filter-suspension-deposit feeder, mostly unprotected and with little or no flexibility. The least sensitive species (group 1) were those vagile species that actively crawl

Table 2
Biological traits and criteria used for the sensitivity assessment.

TRAITS	SCORE	CRITERIA
MAXIMUM SIZE	1	Small (<2 cm)
	2	Medium (2–10 cm)
	3	Medium-Large (11–50 cm)
	4	Large (>50 cm)
LONGEVITY	1	< 5 years
	2	5–10 years
	3	11–50 years
	4	> 50 years
MOTILITY	1	Swimmer
	2	Crawler
	3	Burrower and/or occasional crawler
	4	Sessile
ATTACHMENT	1	None (vagile)
	2	Occasional displacement
	3	Temporary
	4	Permanent (sessile)
BENTHIC POSITION	1	Burrowing
	2	Surface
	3	Emergent (> 20 cm)
FEEDING MODE	1	Scavenger and/or carnivorous
	2	Predator, omnivores
	3	Deposit-feeder and/or suspension-feeder
	4	Filter-feeder
FLEXIBILITY	1	High (>45º) and/or vagile organisms
	2	–
	3	Low (10–45º)
	4	None (<10º)
FRAGILITY	1	Hardshell
	2	Strong
	3	No protection
	4	Fragile shell
BODY FORM	1	Flattened (dorsally and laterally)
	2	Globular or Mound
	3	Erect, Stalk and tree-like
	4	Planar erect

and/or swim near the surface, mostly carnivorous and/or scavengers with longevities of less than 10 years and medium and small sizes (< 10 cm). Species with intermediate sensitivities showed intermediate trait patterns between the two groups described above.

To calculate the sensitivity of species to longline fishing, and because there is no already defined index combining the characteristics of the species to assess sensitivity of species to this type of fishing, we selected from all traits only 3 (maximum size, attachment and body form). The selection of the traits was based on the general knowledge of longline impacts on epibenthic communities [51,131,133,152] and they reflect the resistance of the species to this fishing gear, rather than their recovery capacity. As longline fishing generates less direct damage on the environment than trawling and changes on benthic communities are less detectable [32,133], we classified the species only into three groups of sensitivity (lowest, medium and highest sensitivity), according to their response to this activity (Supplementary Table 2). The most sensitive species (group 3) were those sessile species, permanently attached, with large sizes (>50 cm) and stalked, tree-shaped and erect body shapes, including erect planar forms. The least sensitive species (group 1) were those actively mobile and/or swimming species, with a flattened or globular body shape and even sessile and attached species but of small size (< 2 cm). Species with intermediate sensitivity showed intermediate trait patterns between the two groups described above: sessile and permanently attached species with stalked, tree-shaped and erect body shapes but of medium and medium-large size (2–50 cm) and vagile species with globular or mound body shape and medium-large size.

In a next step, sensitivity to trawling or long-line fishing was calculated per sample as Sensitivity $= \frac{\sum Ni \ x \ Bi}{Ntotal}$, where Ni is de number of individuals of the species i, Bi is the sensitivity value of the species i and Ntotal is the total number of individuals in the sample. Finally, sensitivities of each habitat to both types of fishing were calculated as the round average sensitivity of all the samples from each habitat to each type of fishing. Differences among habitat sensitivities were tested with the non-parametric Kruskal-Wallis test [86], and when they were detected, pairwise "post-hoc" Wilcoxon rank sum test (method = holm) were run to identify the habitats responsible for such differences.

Sensitivity maps were built by giving each grid cell the sensitivity value of the habitat present according to the continuous raster map of all benthic habitats.

2.4. Anthropogenic pressures data

The distribution of effort for the most frequently gears used that have the greatest potential to cause physical disturbance to benthic habitats such as otter trawl and set bottoms long-line (Supplementary Fig. 2) were examined. Fishing effort data was collated for all fishing vessels higher than 15 m in length operating in the seamount during 2010–2012. Spatial distribution of their activity was obtained using logbook data to identify the fishing gear and the Vessel Monitoring System (VMS) datasets to know the location of the fishing vessel at regular intervals of two hours (ping). These two data sources were provided by the Spanish Ministry of Agriculture, Fisheries and Food.

Global Positioning System-GPS location data from VMS and type of gear from logbooks were linked using ship code and trip date fields. Filtering and processing techniques used to remove pings not related to fishing activity were applied [77,110] and only effective trawling time of the nets on the bottom was considered as effort for the assessment of otter trawl while for longline, effort was considered to be only the time allocated to longline retrieval. These effective times of fishing were defined based on the working speed ranges of the vessels according to the frequency distribution of the average speed of the vessels that used each type of gear [77]. To obtain the spatial distribution of time of fishing by year, all the times of all the pings located in the same grid were added together, using a 250 × 250 m grid.

The three raster maps from each year were combined in a unique

map of pressure intensity by adding the values of the three years. In order to identify those habitats that were subjected to greater fishing pressure, for each gear, the percentage of the fishing effort (time) registered in each habitat was calculated. Different levels of fishing effort were defined by using the quartiles, so that effort was divided into 6 levels, from no effort to very high level of effort. The distribution of the different levels of fishing effort was overlapped with the distribution of the habitats, in order to assess the extent of the area of each habitat potentially impacted by fishing activities, and hence, the relative frequency of grid cells subjected to each level of fishing pressure was assessed for each habitat.

2.5. Disturbance maps

Disturbance refers to the physical action of the gears, both trawl nets and fishing lines, on the benthic communities. Disturbance distribution maps per pressure type, trawling and long-line fishing, were obtained by combining habitat's sensitivity and pressure maps, according to the scheme and disturbance matrix developed by Elliot et al. (2018) which categorize grid cells in 9 different levels of disturbance. In this matrix, the calculation of the value of disturbance (D) is obtained by applying the following equation: $= b + \frac{ab}{b}$, where b is sensitivity and a is pressure. Weighting the values, these authors reflected that the low sensitive benthic habitats were less affected by pressure while highly sensitive benthic habitats were more affected by pressure.

Nine and seven distinct levels of disturbance from trawl and long-line fishing, respectively, were calculated. The distribution of the different levels of disturbance was overlapped with the distribution of the habitats, in order to assess the extent of the area of each habitat disturbed by fishing activities.

All data analyses were performed in R 3.2.4 [141].

2.6. Potential scenarios and its application to management

Distribution and surface covered by each habitat are defined by the threshold used when modelling to translate the predicted probability of presence of each habitat into a presence-absence classification map. Since the results obtained by applying the methodology proposed in this study depend, in the first instance, on the distribution of habitats and their coverage in the study area, three other thresholds in addition to prevalence were used to delineate benthic habitats distribution (Supplementary Table 1) in order to test the methodology in different scenarios.

Two of the three thresholds (quantile 10 and spec-sens) studied presented very similar values to those obtained with prevalence and showed almost the same locations for biogenic habitats throughout the study area (Fig. Supplementary 3). However, a threshold (kappa) showed a more limited distribution for most biogenic habitats, increasing the proportion of area covered by non-biogenic habitats. Therefore, disturbance analyses carried out in this study were repeated using the threshold kappa to define the distribution of benthic habitats and results compared with those obtained using prevalence. While prevalence is the threshold at which modeled prevalence (the overall proportion of locations where the variable is predicted to be present) is closest to observed prevalence, kappa is the threshold at which the kappa statistic is maximized and therefore, the proportion of correctly classified locations after accounting for the probability of chance agreement is the highest.

As a complementary spatial analysis based on these two scenarios that show two different distributions of benthic habitats, areas on the Seco de los Olivos were classified to define both, priority conservation and potential recovery areas. Each pixel was assigned a value from 1 to 3 depending on whether the two thresholds, only one or none respectively, identified it as a potential area for the distribution of a biogenic habitat based on environmental conditions. These areas, evaluated

together with areas characterized by different levels of disturbance, can provide a useful overview to inform marine spatial planning in this marine protected area.

3. Results

3.1. Habitat sensitivity

When comparing biogenic and non-biogenic habitats in the same substrate type (soft, rhodoliths and hard) and depth range (circalittoral and bathyal), biogenic habitats showed significantly greater sensitivity to both trawling and longlining than non-biogenic habitats (Chi-square = 1141.1; p-vale <2.2e-16) (Fig. 2; Table 3). In the case of trawling, the most sensitive habitats were the biogenic habitats on the circalittoral (Habitats 2-'rock-alcyonacea' and 3-'coralligenous-gorgonians') followed by the other biogenic habitats. Only one habitat (the non-biogenic 'SBcirca- Circalittoral soft bottoms') showed a sensitivity value equal to 1, indicating a non-sensitive habitat. In the case of longline fishing, all biogenic habitats were shown to be sensitive, while all non-biogenic habitats were shown not to be sensitive, except for habitat HBbat-Bathyal hard bottoms, which also obtained a sensitivity value equal to two. Although the Hab-7 *Isidella elongata* showed a slightly higher value, none of the sensitive habitats reached the highest level of sensitivity.

The most sensitive benthic habitats for both trawling and longlining are distributed mainly on the top of the central bank and on the pinnacles of the surrounding lateral elevations (Fig. 3).

3.2. Anthropogenic pressure

Fishing effort was patchily distributed throughout the study area (Fig. 4). Trawling effort, specifically, although widespread distributed throughout the seamount, was especially noticeable in the eastern side of the study area and above all, on the trawling grounds located north and south of the study area. Nevertheless, patchy areas without trawling effort (level 0) were also found, possibly indicating areas not suitable for trawling. Distribution of the longlining effort, however, was clearly concentrated on the crests of the surrounding ridges as well as on the summit of the central guyot.

All the habitats described on this seamount, both biogenic and non-biogenic, were subjected to bottom fishing (Fig. 5). Habitat 1-'maërl-alcyoniina' was found to have the smallest area exposed to trawling effort, with 89.4% of its area of distribution not being subjected to fishing (effort level=0), followed by habitats 'MBrhod- Circalittoral bottoms with rodholiths' (75.3%) and 'HBcirca- Circalittoral hard bottoms' (75.2%). On the contrary, habitats with the highest percentage of its distribution subjected to different levels of trawling effort were the habitat 6-'mud-pennatulids' (62.8%), 'SBbat- Bathyal soft bottoms' (52.7%), 'SBcirca-Circalittoral soft bottoms' (50.3%;) and habitat 8-'sand-pennatulids' (prevalence:47.6%).

The results obtained from the analysis of the longline data showed that habitats on soft bottoms, both biogenic and non-biogenic, had the lowest percentage of their distribution subjected to longline fishing: SBcirca (63.8%), hab 6- 'mud-pennatulids' (61.9%), hab 7- 'mud-bamboo corals' (61.3%), SBbat (59.5%) and hab 8- 'sand-pennatulids' (55.7%). In contrast, habitats with the largest percentages of its area of distribution subjected to fishing were those biogenic on circalittoral bottoms with rhodoliths and bathyal hard substrates, such as habitat 1-'maërl-alcyoniina' (81.3%) and habitat 4- 'rock-gorgonians and giant sponges' (74.3%).

Based on the images from the ROV transects, while the persistence in good conditions of larger colonies of species such as *Paramuricea clavata*, *Eunicella verrcuosa* or *Madrepora oculata* and sponges such as *Asconema setubalense* on rocky bottoms may reveal areas unexposed to fishing, images of broken, isolated and scattered colonies of *M. oculata*, giant sponges *A. setubalense* bent, gorgonians such as *Acanthogorgia hirsuta* and black corals such as *Leiopathes glaberrima* and even crustaceans and
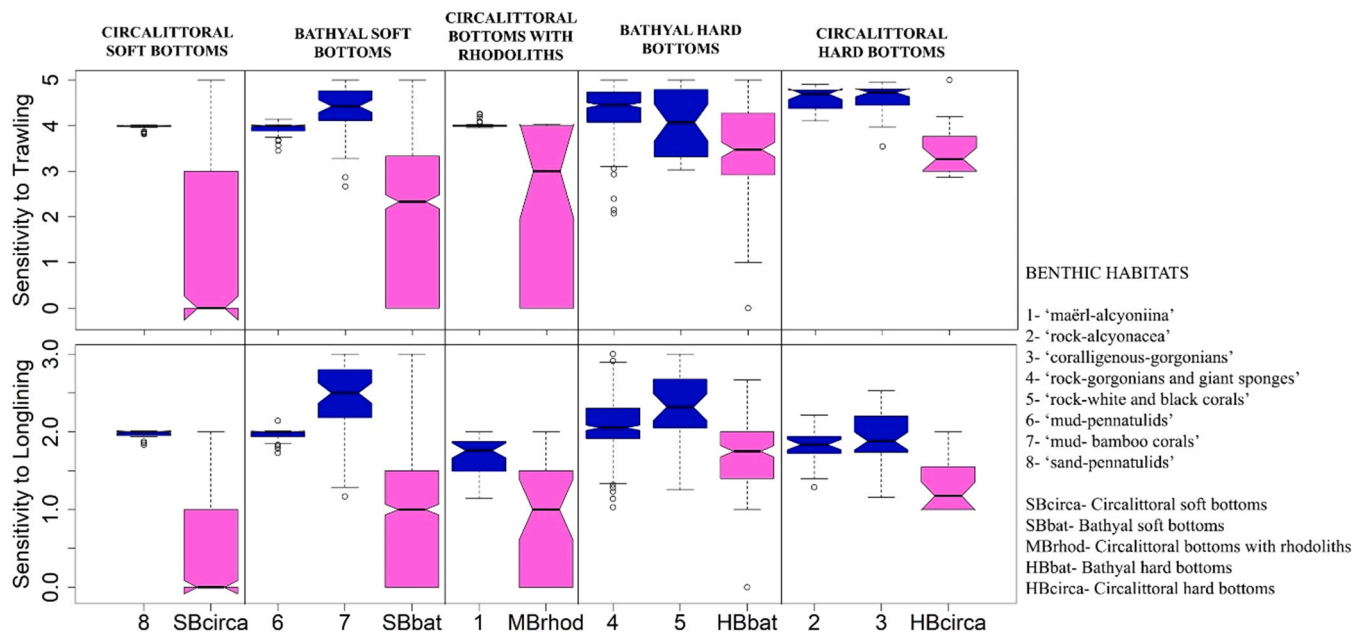
Fig. 2. Sensitivity of the benthic habitats to trawl and longline fishing. Habitats with a biogenic component (in blue) and without a biogenic component (in fuchsia) were compared for the different categories of depth (circalittoral and bathyal) and bottom type (soft, rhodoliths and hard).

Table 3

Habitat sensitivity to trawl and longline fishing. The names in quotation marks indicate the short name of the habitats used throughout the text and figures.

BENTHIC HABITAT	NAME	SENSITIVITY TO TRAWLING	SENSITIVITY TO LONG-LINE
BIOGENIC HABITATS			
1	'maërl-alcyoniina'	4	2
2	'rock-alcyonacea'	5	2
3	'coralligenous-gorgonians'	5	2
4	'rock-gorgonians and giant sponges'	4	2
5	'rock-white and black corals'	4	2
6	'mud-pennatulids'	4	2
7	'mud- bamboo corals'	4	2
8	'sand-pennatulids'	4	2
NON-BIOGENIC HABITATS			
SBcirca	Circalittoral soft bottoms	1	1
SBbat	Bathyal soft bottoms	2	1
MBrhod	Circalittoral bottoms with rhodoliths	2	1
HBcirca	Circalittoral hard bottoms	3	1
HBbat	Bathyal hard bottoms	3	2

urchins evidently entangled and covered by a high number of fishing lines and nets, revealed areas exposed to both fishing types (Fig. 6). Furthermore, wide bands of dead coral debris at the base of rocky areas covered by fishing debris (lost lines, ropes, weights, nets, anchors, etc.) as well as damaged gorgonians (e.g. *Acanthogorgia hirsuta, Isidella elongata, Leiopathes glaberrima*) with few irregular branches provided additional evidence of widespread fishing disturbance in the area. This is even more evident in soft bottoms, where the occurrence of smaller colonies of the bamboo coral *I. elongata* in low density, with a low number of branches, many of them dead and covered by parasitic epibionts, in areas marked by trawling scars (Fig. 7), may indicate areas impacted by fishing activities.

The assessment of the fishing effort (time and area covered) carried out on each benthic habitat is shown in Fig. 7. The most heavily trawled habitat was the non-biogenic 'SBbat- Bathyal soft bottoms'. However, the rest of the fishing effort was conducted mainly on biogenic habitats (6-'mud-pennatulids', 4-'rock-gorgonians and giant sponges' and 7-'mud-bamboo corals' and 2-'rock-alcyonacea'). Conversely, fishing time on biogenic habitats was longer for longline fishing, reaching percentages of 71.7%. Almost half of the total effort time (45.6%) was found to be carried out on the habitat 4-'rock-gorgonians and giant sponges'. Considering the area covered by all the studied benthic habitats and the different levels of effort, in 50.1% of the grid cells no trawling and longlining (effort level=0) were registered. The level of trawling effort varied where fishing was registered, from level 1 in 24.2% of the grid cells to level 5 that occurred only on 1.4% of the grid cells. The distribution of the different levels of effort where longlining was registered was 6.8%, with this maximum value corresponding to level 5 of effort.

3.3. Habitat disturbance

The nine possible disturbance levels were found (Fig. 8) and disturbance distribution maps per pressure type, trawling and long-line fishing, were obtained (Fig. 9) by using the disturbance matrix and scheme developed by Elliot et al. (2018).

Some degree of disturbance from trawling was recorded in 49.9% of the study area (Fig. 8). The nine possible levels of disturbance obtained by the disturbance matrix were found, and 33.4% of the area was affected by a disturbance level of less than 5, while 16.5% was affected by the higher levels. From the total area, in 52.5% no degree of disturbance from longline fishing was registered. However, in the rest of the area, only levels of disturbance from 1 to 4 were found. The area affected by different levels of disturbance varies between 4.1% (level 3) and 17.1% (4).

The distribution of the areas of the highest disturbance followed a pattern similar to that of fishing effort (Fig. 9). The greatest disturbance from trawling were found throughout the seamount, with a higher concentration on some dispersed points around the central summit and in the north-eastern area, whereas the highest levels of disturbance from longlining were clearly concentrated on the crests of the surrounding ridges as well as on the summit of the central guyot.

All the habitats had part of their distribution disturbed by both trawling and longlining (Fig. 10). Clearly, the area covered by biogenic
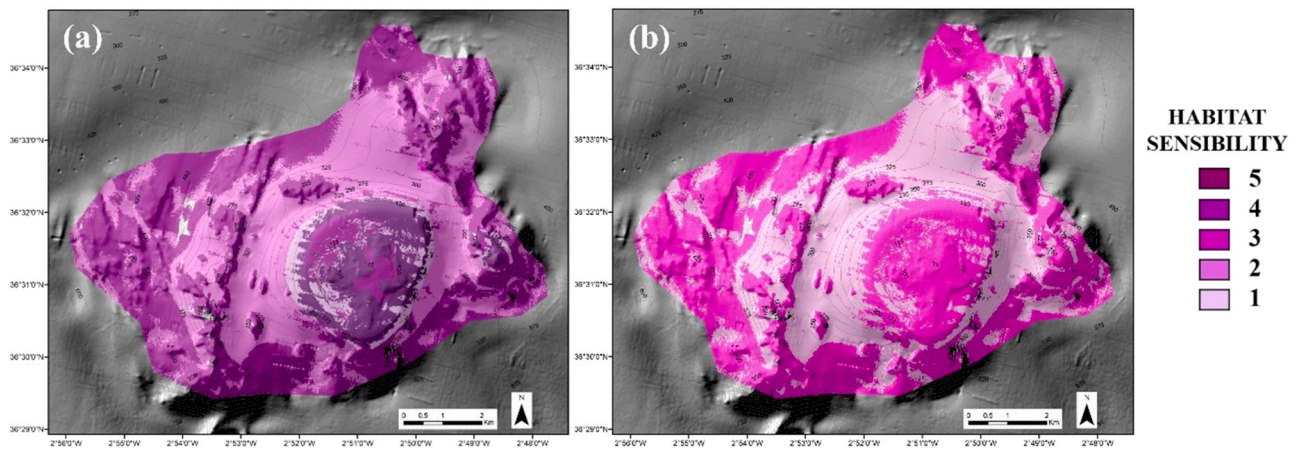
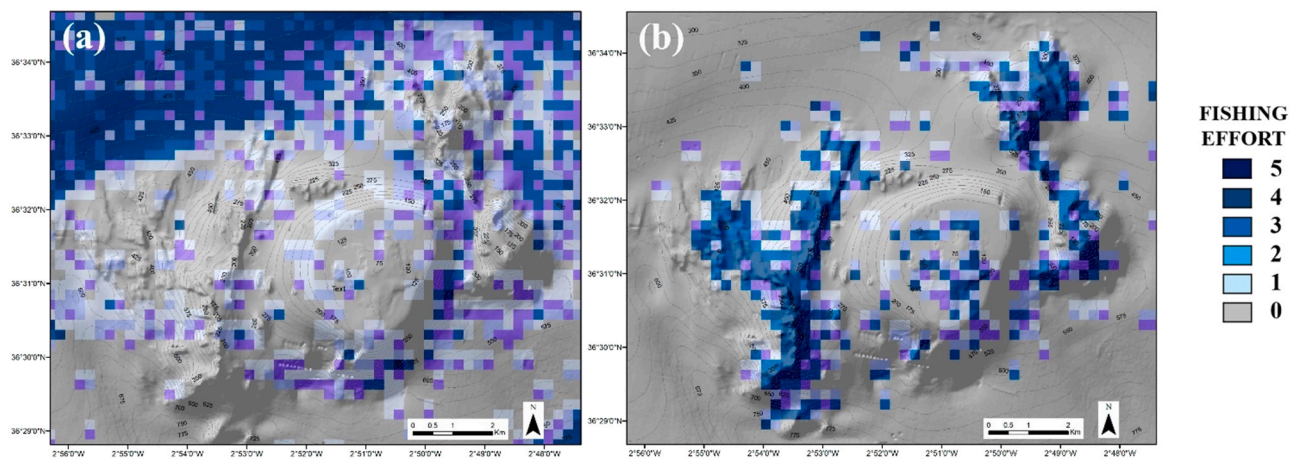**Fig. 3.** Distribution of benthic habitat sensitivity to (a) trawling and (b) longlining.

Fig. 4. Fishing distribution maps: (a) trawling and (b) longlining.

habitats reached higher levels of disturbance than the area covered by non-biogenic habitats. For trawling, the habitat 1-'maërl-alcyoniina', was the habitat whose area was found to be more undisturbed (89.4%). However, the area covered by biogenic habitats on circalittoral hard bottoms (habitats 3- 'coralligenous-gorgonians' and 2- 'rock-alcyonacea') were the habitats that reached more area of their distribution under the maximum level of disturbance (level 9), with percentages of 9.6% and 7.4%. For longlining, habitats on bottoms with rhodoliths and hard substrates, had the highest extent of disturbed areas, with habitat 1-'maërl-alcyoniina' showing the highest percentages of its distribution disturbed (81.3%). Habitat 4- 'rock-gorgonians and giant sponges' was found to have the highest area (53.8%) under the maximum level of disturbance (level 4).

3.4. Potential scenarios and its application to management

Comparing the benthic habitat distribution maps obtained with the prevalence and kappa thresholds, the prevalence map showed larger areas of overlap among the distribution of such biogenic habitats obtained individually from the models (Fig. Supplementary 4). These overlapping areas are concentrated mainly at the central bank summit, where habitats of coralligenous and rhodoliths are distributed, and at the top of the surrounding ridges, where rocky habitats with corals and sponges are encountered (Fig. Supplementary 3). In each pixel where several biogenic habitats overlapped, the one with the highest probability of occurrence was selected for the final single continuous map. However, the map obtained with kappa showed a more limited distribution of biogenic habitats and hence, some non-biogenic habitats such as circalittoral bottoms with rhodoliths and circalittoral and bathyal hard bottoms, were more widespread. In this last map, only a slighter overlapping among biogenic habitats was found, especially on the central guyot. In fact, the 'prevalence map' showed that in 72.63% of the study area there was not overlap among biogenic habitats whereas this percentage increased to 97.40% on the 'kappa map', showing two different scenarios on the seamount.

Therefore, the extent occupied by the most sensitive habitats varies depending on the threshold used (prevalence versus kappa) to perform the distribution modelling (Figs. 11(ii) and 12(ii)). However, since the distribution of the areas of the highest disturbance followed a pattern similar to that of fishing effort, there were no substantial differences in the distribution of the areas disturbed when using either threshold.

Similar to what occurred when using the prevalence threshold, some degree of disturbance from trawling was recorded in almost half of the study area (49.6%) when using the kappa threshold and the nine possible level of disturbance were found (Fig. 11); however, the percentage of the are affected by the higher disturbance levels (from level 5 to level 9) dropped from 16.5% in the prevalence scenario to 4.5% in the kappa scenario. Likewise, in 51.5% of the total area, no degree of disturbance from longline fishing was registered when using the kappa threshold, a percentage similar to the one we found when using prevalence (52.5%) and only disturbance levels below 5 were recorded. However, the percentage of the are affected by levels 3 and 4 dropped from 21.1% in the prevalence scenario to 12.1% in the kappa scenario (Fig. 12).
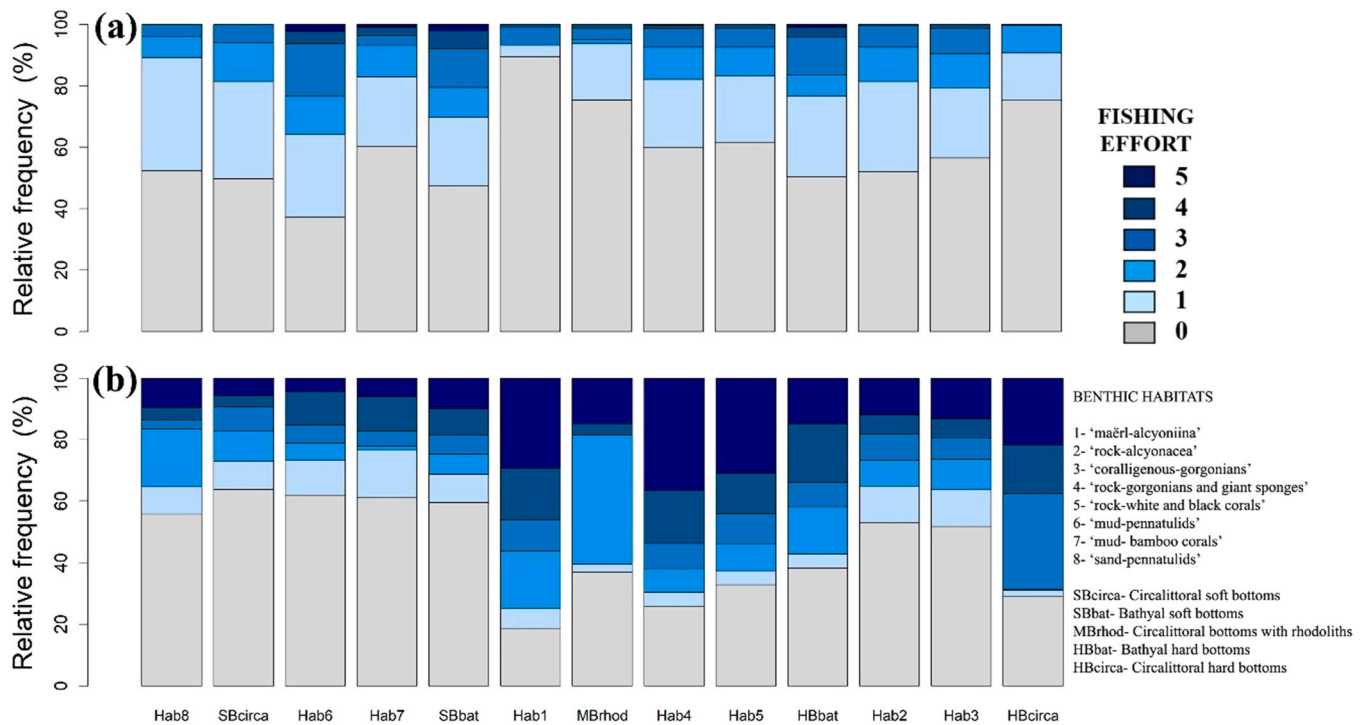
Fig. 5. Relative frequency of grid cells of each benthic habitat subjected to the different fishing effort levels: (a) trawling, and (b) longlining. Effort level 0 included all the grid cells where no fishing was registered. The relative effort is for each type of fishery and the values are not comparable between them.

Based on the forecasting scenarios obtained with the two thresholds, three different areas were classified and mapped (Fig. 13): (1) 'core zone', where both thresholds predicted the existence of biogenic habitats, were located at the top and central area of the bank and surrounding ridges; (2) 'transition or buffer zone', where only one of the thresholds predicted the existence of biogenic habitats, were located around the core zone, and (3) 'zone without biogenic habitats', where both thresholds predicted the absence of biogenic habitats were located mainly between the central bank and the lateral ridges.

4. Discussion

The spatial analyses performed in this study constitutes a practical application of a methodology that can be used to implement management measures focused on achieving a balance between sustainable fisheries and habitats conservation and hence, for compliance with the various European directives related to the management of marine resources and habitats protection.

4.1. Methodological and conceptual approach

The proposed methodology is applied in this study to habitats characterized by epibenthic megafaunal communities recorded by ROV sampling on a seamount, using some biological and ecological characteristics of the species to assess their sensitivity to fishing activities. A more complete understanding of this marine ecosystem that includes the study of other compartment such as infauna communities as well as progress in the knowledge of various characteristics of the species most relevant to recovery success (other life-history traits such as fecundity, pelagic larval dispersal and settlement factors, population connectivity, spatial distribution, structural complexity, and the potential for regime shifts) [13], would allow progress to be made in evaluation of potential measures for future biodiversity conservation, habitats recovery and an appropriate management of activities in this MPA. However, this is especially complicated in areas of difficult access such as the deep-sea and therefore, unachievable in the short term.

The analysis of sensitivity of benthic communities showed that biogenic habitats are more sensitive to trawl and longline fishing than non-biogenic habitats. This is explained by the high densities of habitat-forming species (HFS) that characterized biogenic habitats, mainly cnidarian (Alcyonacea, Antipatharia, Scleractinia and Pennatulacea) and porifera (Hexactinellida), considered to be the most susceptible to disturbance since these are all fragile three-dimensional sessile species with high longevity and slow growth rates, long reproductive cycles and low rates of recruitment [5,29,88,116,166]. The contribution of the HFS to the sensitivity of these biogenic habitats masks the sensitivity provided by the rest of the associated community. Although we also calculated the sensitivity of the habitats using only key species, analyses based on the entire biological community better reflected species composition and abundance of the non-biogenic habitats as these analyses resulted in a higher variability of sensitivity values for these habitats.

Trawling is well known to modify benthic communities, even in areas with low fishing intensity, by reducing the abundance of long-lived and slow recruiting species, which are replaced by fast-growing opportunistic species ([33,116]; González-Irusta, 2018). For long-line fisheries, some studies have reported quite high effects on benthic communities [54,124,165], nevertheless, their impact is believed to be less deleterious than trawling [32,133]. Accordingly, much greater longline effort than trawling is required to cause similar damage to sensitive benthic habitats and therefore, changes in communities are not as detectable; even, similar vulnerable species compositions can be found within the community after many years of longline fishing [133]. Considering that the study area has traditionally and continuously been a fishing area where no specific management measures exist, different degrees of changes in species composition are expected: in areas subjected to trawling, both changes in the relative abundance of species and even their disappearance, as well as changes related to the early stages of ecological succession are expected to be detectable and hence, the sensitivity of species to trawling was assess based on their resistance and recovery capacities [116,136]; however, only traits related to resistance were selected when assessing sensitivity of species to longlining since in
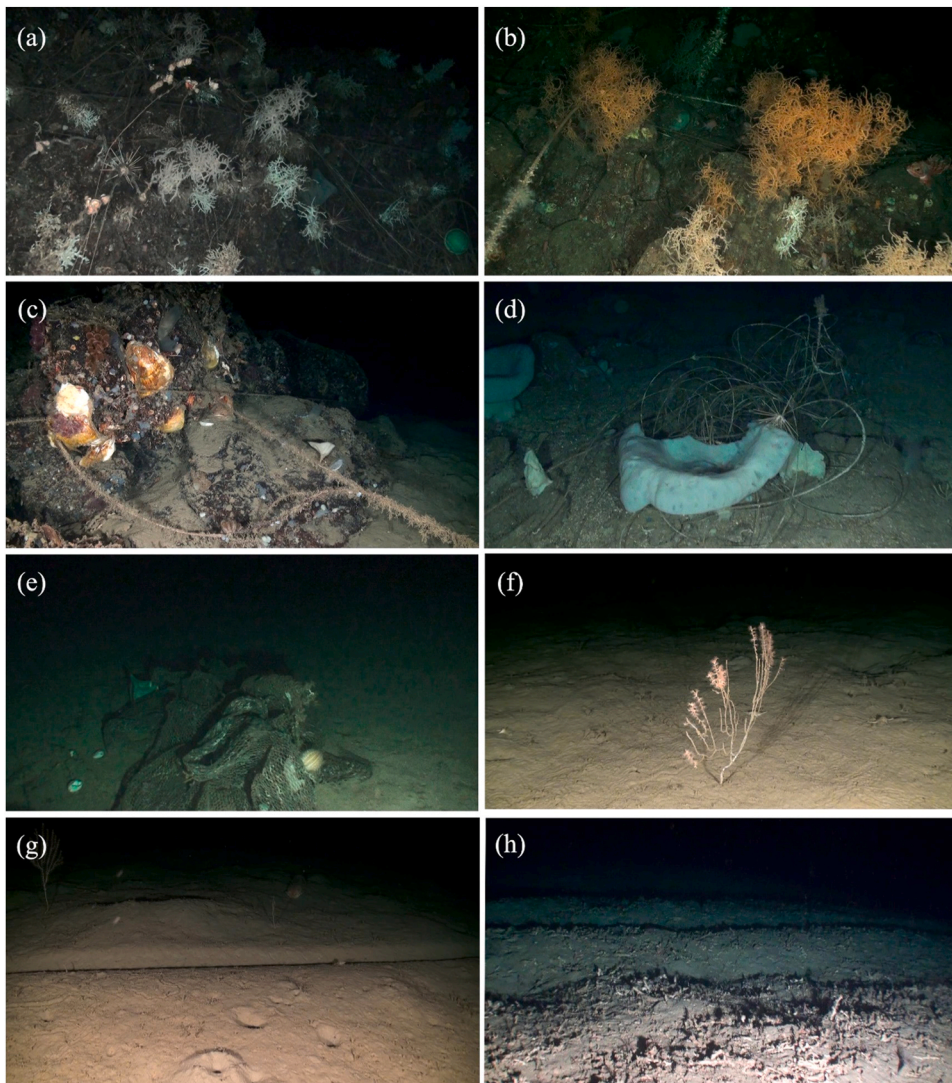
Fig. 6. ROV images showing impacts from fishing in the study area: species colonies entangled by fishing line: (a) *Madrepora oculata*, (b) *Leiopathes glaberrima* and *Madrepora oculata*, (c) *Neopycnodonte zibrowii* giant oyster reef, (d) broken pieces of *Asconema setubalense;* (e) a sea urchin and a piece of *Asconema setubalense* entangled in an derelict net, (f) *Isidella elongata* colony partially covered by epibionts, (g) a trawl mark within the benthic habitat characterized by *Isidella elongate*; and (h) dead coral framework crossed by trawl marks.

areas subjected to this type of fishing, only changes due to the disappearance of individuals are expected to be found.

To find areas that contain habitats vulnerable to anthropogenic activities and inform spatial management decisions requires, in addition to knowing the sensitivity of the habitats to physical damage, to know their exposure to external factors [116]. Although sensitivity and vulnerability are sometimes used as synonymous, sensitive habitats to fishing are only vulnerable to this activity in those areas where their distribution overlap [116]. Sensitive habitats that are not vulnerable today may become vulnerable habitats if the distribution of fishing effort changes in the future. The approach of this study makes it possible to predict the effect of disturbance that would exist under different possible management scenarios of fishing activities.

The overlap of habitat distribution and fishing effort to allow predicting areas of maximum and minimum disturbance was made on the basis of models, which forces us to take the limits with some caution. On the one hand, habitat modeling techniques generate predictions that provide a probability of presence that needs to be translated into a presence-absence classification map by a choice of a threshold. Both, model accuracy and predicted prevalence can vary depending on the threshold used, so it should be chosen to match with each map intended use [62]. In our study, using the threshold prevalence, the prediction responded to a more precautionary approach, assigning greater area of distribution to biogenic habitats (more sensitive habitats), while using

the kappa threshold, we obtained a more limited prediction for these biogenic habitats, more restricted to the core areas of the habitats. We believe that the best way to assist with spatial management advice is by proposing comparative scenarios based on both thresholds, offering a range of plausible scenarios to managers and stakeholders. On the other hand, benthic habitat and fishing effort distribution data were obtained at different scales. Habitats were identified and characterized using an average sample size of 13 m. However, the use of VMS data requires the acquisition of position data every 2 h for European Union-EU vessels fishing in EU waters, meeting the mandated in European legislation for ensuring compliance with the rules of the Common Fisheries Policy [55], which implies resolutions of about 3 km. This coarse resolution limits the accuracy in the assessment of physical disturbance over each benthic habitat, especially in border areas between soft and hard sediments, highlighting the need to have more demanding regulations that provide information on a smaller scale.

Finally, in order to have a truly complete picture of the impact of fishing on benthic habitats, additional to professional fishing, artisanal and recreational fishing data from the Seco de los Olivos needs to be acquired and analyzed. Although changes in the distribution of effort and areas subject to these activities are not to be expected since they use the same fishing grounds, this could probably correct a possible slight underestimation of effort levels in areas where longline fishing operates, while no substantial changes in trawling levels are expected.
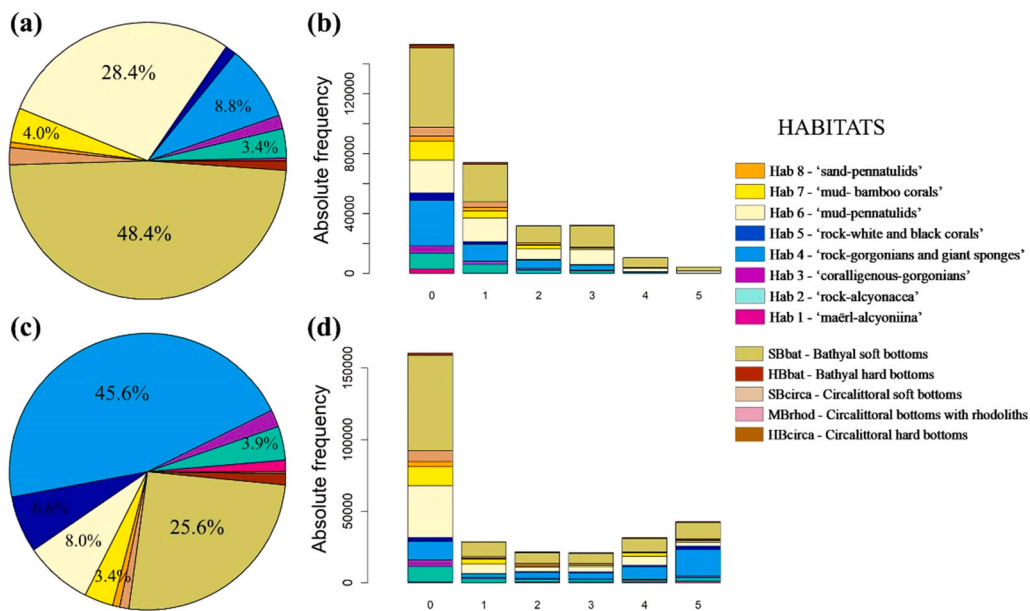
Fig. 7. Fishing effort carried out on each benthic habitat: Percentage of time of (a) trawling and (c) longlining; and absolute frequency (total number of grid cells) distribution of effort levels of (b) trawling, and (d) longlining.
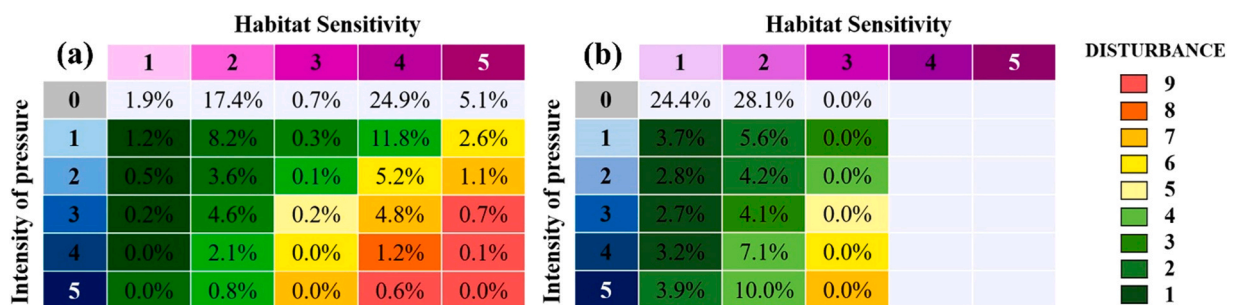

Fig. 8. Habitat disturbance assessment from (a) trawling and (b) longlining, using the combination of sensitivity levels and pressure effort in a disturbance matrix developed by Elliot et al. (2018). The area occupied (%) by each level of disturbance was in added.
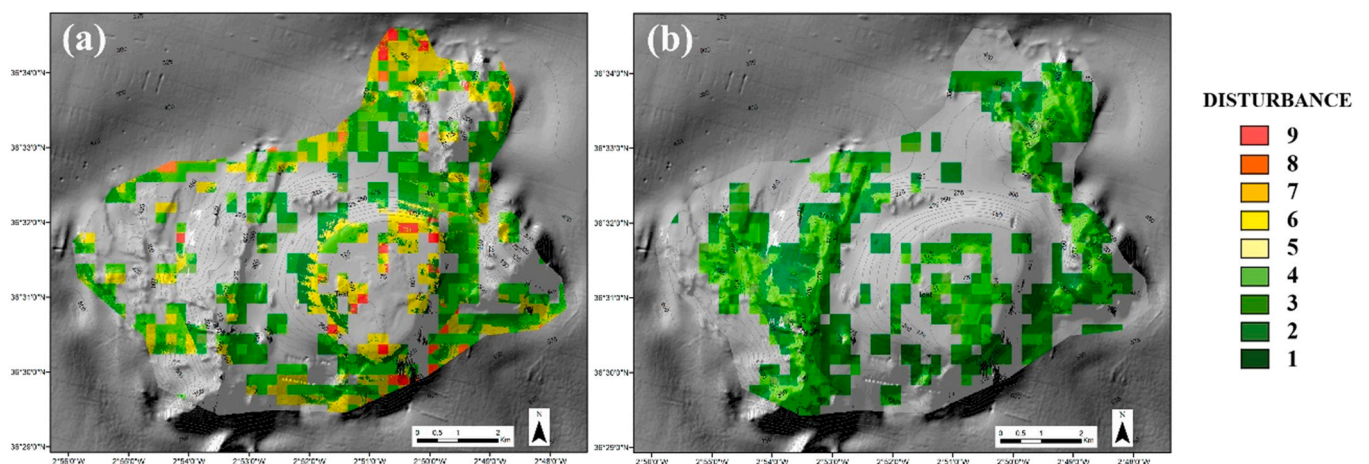

Fig. 9. Disturbance distribution maps from (a) trawling and (b) longlining, using categories ranging from 1 to 9, with 9 representing 100% disturbance.

4.2. Habitat disturbance

Trawling effort was carried out mainly on soft bathyal substrates, both biogenic and non-biogenic. Habitats with the relative largest area affected by trawling was the habitat characterized by the sea pen *Kophobelemnon stelliferum*, which also was among the habitats that reached the highest levels of disturbance, along with the circalittoral biogenic habitats on hard substrate. Few dense facies of *K. stelliferum*
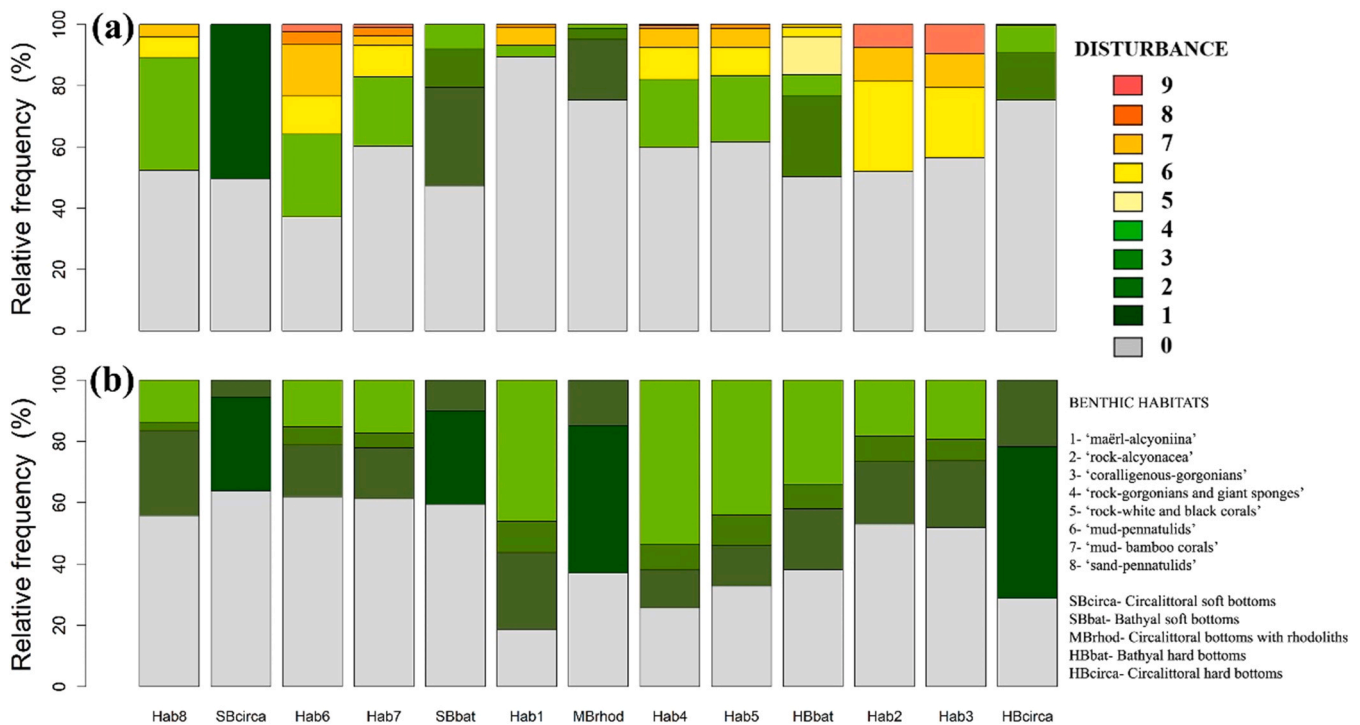
Fig. 10. Relative frequency of grid cells of each benthic habitat disturbed by fishing: (a) trawling, and (b) longlining. Disturbance level 0 included all the grid cells where no fishing was registered.

have been described for the Mediterranean, probably because this fragile species has disappeared due to trawling activity and at present their occurrence is limited to areas where this activity is not possible [71,118]. The trawlable soft bottoms of the study area, interpolated with rocky bottoms, are very limited [1], which would explain why this habitat continues to exist, even though under fishing pressure. The habitat characterized by the bamboo coral *Isidella elongata* also on bathyal soft bottoms showed lower disturbance levels than that of *K. stelliferum*, even though both habitats revealed similar sensitivity values, which can be explained by its lower vulnerability (i.e its sensitivity plus its exposure to trawling). This situation is contrary to the one described for the facies of this species on deep-sea soft bottoms of the Mediterranean, which have suffered substantial reductions due to intense trawling [30,120] and, their widespread distribution throughout the Mediterranean in the past [119], have, at present, almost completely disappeared [49,56,120,134,153]. The absence of *I. elongata* from extensive areas under trawling pressure on the Seco de los Olivos are likely explained by the effect of chronic bottom trawling activity in the area, leaving only a few scattered colonies. Cartes et al. [30] found that even low trawling pressure is enough to remove almost all the colonies of this species from a pristine ground. Those areas were classified in this study as the non-biogenic habitat SBbat, instead of the biogenic habitat hab 7- 'mud- bamboo corals', and as a result, the overlap between habitat distribution and pressure was smaller. These areas host a high potential as recovery areas for this highly threatened species and should be areas of special interest in the development of any management plan of the MPA.

Circalittoral biogenic habitats on hard substrate such as coralligenous and rocky bottoms with alcyonacea species, have also suffered an intense trawling pressure in the Mediterranean [10,59]. The higher levels of disturbance from trawling showed by these habitats on the study area are due to their sensitivity, because even though they have less area under fishing pressure than others, they are the most sensitive habitats found. Likewise, although hard bottoms, especially those found on irregular and abrupt rocky substrates, do not seem to be the most feasible for trawling and we assume that some of the overlap

can be explained by differences in scale between habitat and fishing effort maps, it cannot be ruled out that technological development has allowed this type of fishing to develop on hard bottoms on the deep-sea [61,138] and, especially, on the limits with highly associated diversity [81,87,145]. This, together with their high sensitivity, could explain the disturbance reached in this type of deep substrates characterized by sponges and corals.

Bottom trawling has also been identified as the most severe threats for maërl or rhodolith beds which causes a decrease of the size and coverage of the algae as well as the biodiversity associated [11,18,21,73, 128]. Contrary, Borg et al. [20] and Moranta et al. [122] reported higher abundance and coverage of rhodoliths in areas subjected to trawling. In our study area, despite the biogenic habitat on bottoms with rhodoliths was identified as highly sensitive to both longlining and trawling, it showed to be much less vulnerable to trawling than longlining, as the overlapping area with the fishing effort was smaller for this fishing gear. In fact, the habitats whose distribution was most disrupted by longlining were those on bottoms with rhodoliths and circalittoral hard substrates, both biogenic and non-biogenic, which were also the habitats that reached the highest levels of disturbance. All other hard bottom habitats, especially bathyal biogenic ones characterized by white and black corals, gorgonians, and sponges, also showed high percentage of their area with high levels of disturbance from longlining. Similar results have been obtained in other studies [12,51,61,124,127,144,152], which suggested that bottom longlining negatively affects these vulnerable ecosystems, to the extent that it seems highly likely that there are no pristine deep coral forests that have not been impacted by this activity in rocky fishing grounds of the Mediterranean basin [14]. Although the effects of intense long-lining on sensitive habitats has not been yet significantly detectable [133], it may still represent a serious threat if fishing intensity is high [12,34,124].

Percentage of longlining effort carried out on biogenic habitats and on hard bottoms was relatively higher than for trawling and the lower sensitivity of non-biogenic habitats was also reflected in the lower levels of disturbance from longlining shown by these habitats. Habitat builder species that have large and arborescent growth body forms are
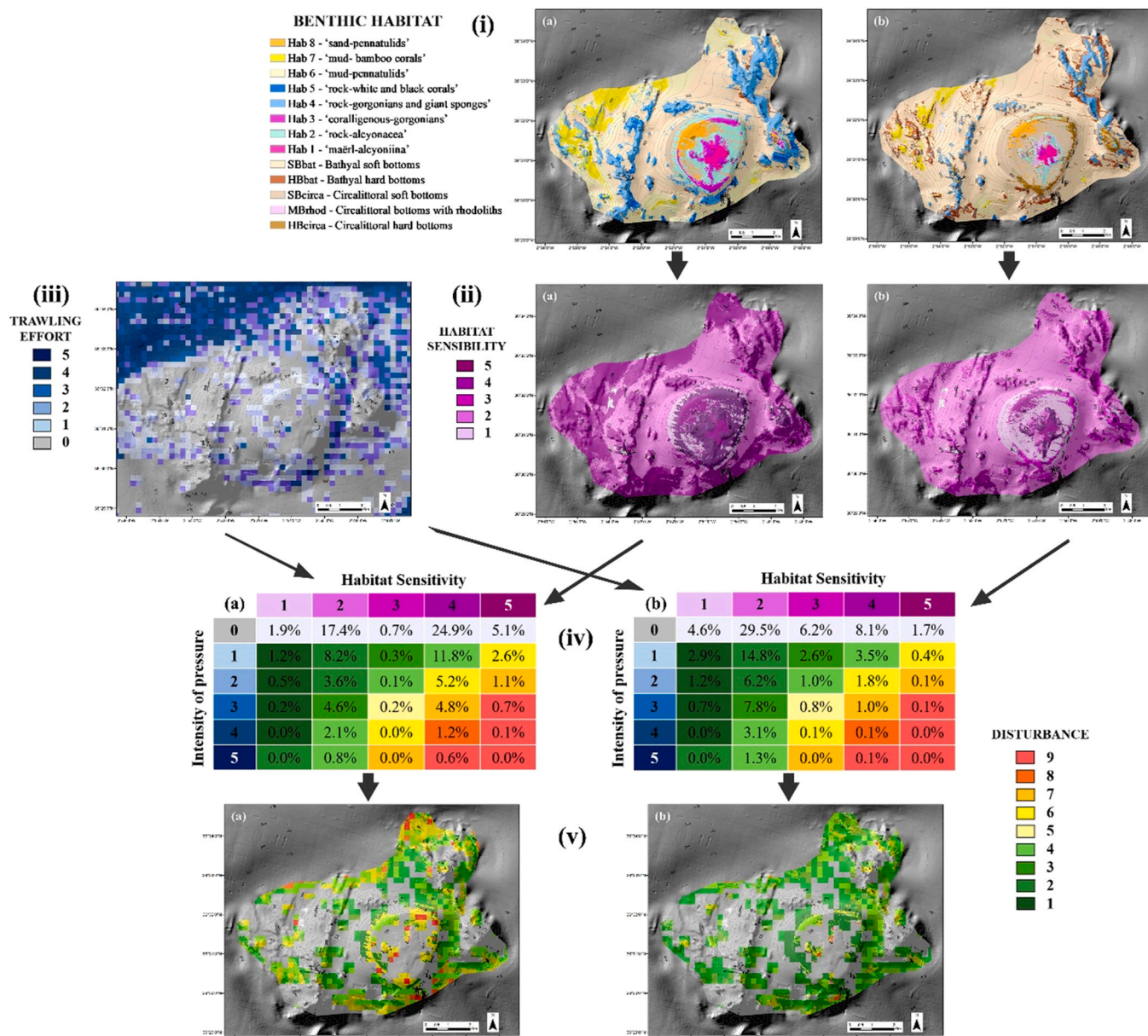
Fig. 11. Methodology applied to obtain habitat disturbance maps from trawl fishing based on the scheme presented by Elliot et al. (2018) and using two different thresholds to model benthic habitats: (a) prevalence, and (b) kappa. Steps required to assess disturbance from fishing activities were: (i) Benthic habitats modelling; (ii) Benthic habitat sensitivity assessments and mapping; (iii) Pressure distribution mapping; (iv) Habitat disturbance assessment using the combination of sensitivity levels and pressure effort in a disturbance matrix, which includes the area occupied (%) by each level of disturbance; and (v) Disturbance distribution mapping using categories ranging from 1 to 9, with 9 representing 100% disturbance. Species were classified into five groups of sensitivity to trawling. Intensity of pressure 0 included all the grid cells where no fishing was registered.

particularly vulnerable to encounter fishing lines. These species are easily entangled on fishing lines, being captured as bycatch or remaining on the bottom with their broken branches or their tissues damaged and being more vulnerable to pathogenic microorganisms colonization and eventually dying [12,14,28,124,152]. In contrast to trawling, the habitats with the smallest area affected by longlining were those on soft bottoms, both circalittoral and bathyal, with null or very low vertical development and structural complexity.

Differences between the most disturbed areas from trawling and from longlining on the Seco de los Olivos were detected. Trawling effort was patchily distributed throughout the study area, whereas longlining effort was clearly concentrated on the crests of the surrounding ridges as well as on the summit of the central guyot. Rocky banks and steep flanks are usually inaccessible and avoided by large trawlers, while they are

important grounds feasible for professional long-liners and recreational fishermen [51,152]. However, trawling was mostly located in soft bottom areas, occupied by both non-biogenic and biogenic habitats. As a consequence of the more widespread distribution of the trawling, the levels of effort reached were relatively lower while the concentration of the longlining effort in more localized areas resulted in relatively higher levels.

4.3. Management scenarios

Conservation, but also recovery and monitoring measures should be implemented in any MPA to promote ecosystem management and fulfil the international directives. All HFS that characterize the biogenic habitats recorded on the Seco de los Olivos are considered as sensitive
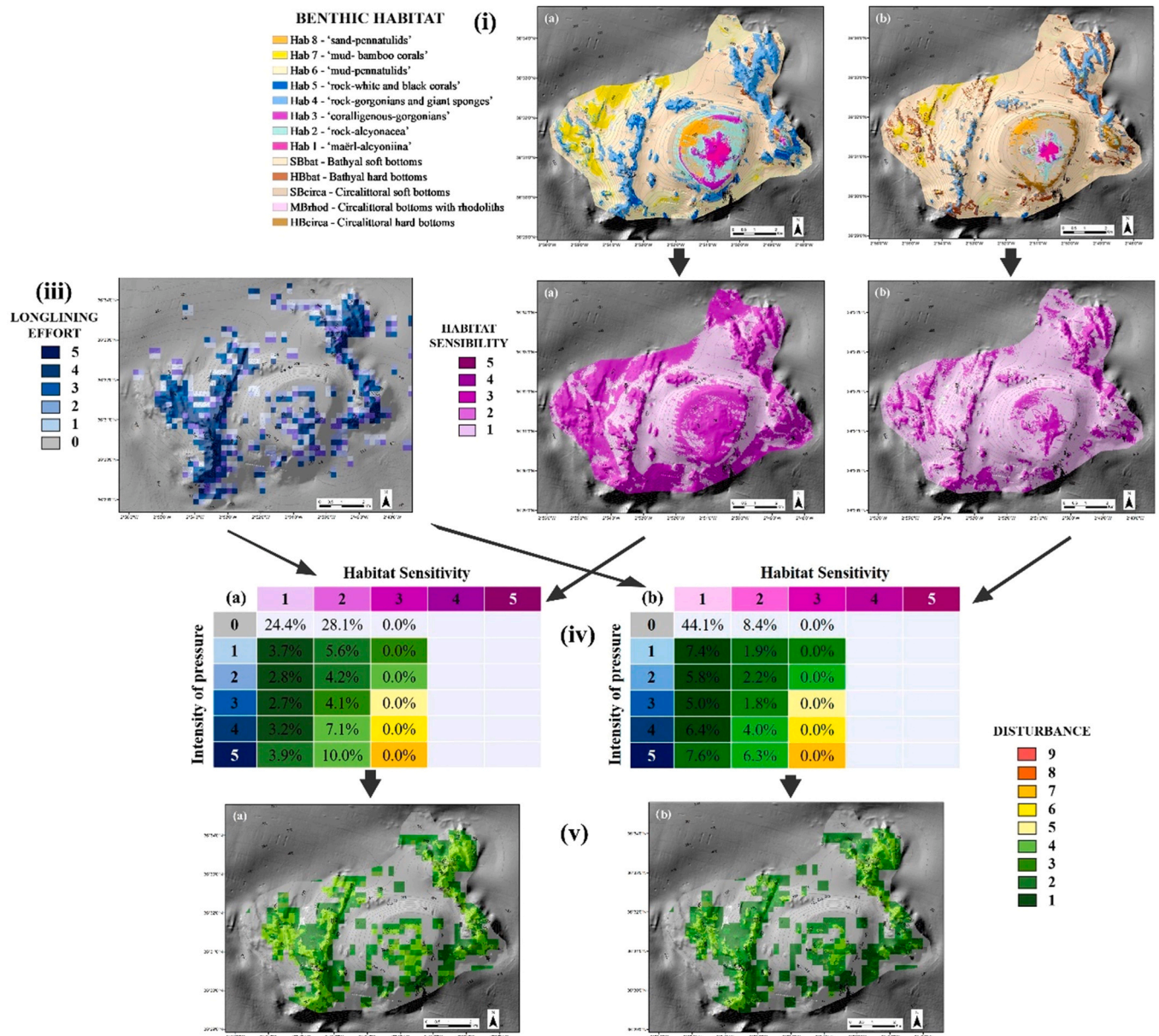
Fig. 12. Methodology applied to obtain habitat disturbance maps from longline fishing based on the scheme presented by Elliot et al. (2018) and using two different thresholds to model benthic habitats: (a) prevalence, and (b) kappa. Steps required to assess disturbance from fishing activities were: (i) Benthic habitats modelling; (ii) Benthic habitat sensitivity assessments; (iii) Pressure distribution mapping; (iv) Habitat disturbance assessment from the combination of sensitivity levels and pressure effort by using a disturbance matrix, which includes the area occupied (%) by each level of disturbance; and (v) Disturbance distribution mapping using categories ranging from 1 to 9, with 9 representing 100% disturbance. Species were classified into only three groups of sensitivity to longlining. Intensity of pressure 0 included all the grid cells where no fishing was registered.

habitats by the General Fisheries Commission for the Mediterranean [65,158] and some of these habitats are considered as priorities of conservation in the HD (92/43/CEE) and Barcelona Convention [161]. The distribution of biogenic habitats, therefore, shows priority conservation areas that can guide the development of zoning within the framework of the management plan.

According to our results that showed that around 50% of the area was disturbed by fishing, evidence of the different levels of pressure were recorded across the study area. This situation contrasts with the healthy state of biogenic habitats of other banks located in the Alborán Sea that have remained relatively inaccessible to fishing pressure, such as Les Cabliers [39] or the Francesc Pagès [114] banks, where well-preserved megabenthic assemblages and almost no sign of fishing footprint was observed. The accessible depth, the proximity to the coast

as well as the topography characterized by a huge diversity of substrates and habitats [14], makes the Seco de los Olivos a fishing ground available to the use of different fishing gears. However, despite the evidence of fishing detected, it is not clear whether communities are today the result of some degree of joint anthropogenic and natural disturbance or whether they are exclusively the result of intense fishing pressure that has already caused long-term changes to benthic communities. In this sense, it is unclear if non-biogenic habitats on the study area are the result of their adaptation to local environmental conditions or the result of a past and continuous fishing effort where sensitive species have already been removed, even becoming locally extinct.

For example, some communities on coarse sediment adapted to frequent natural disturbance, such us that produced by storms and wave erosion, are usually characterized by low species diversity and
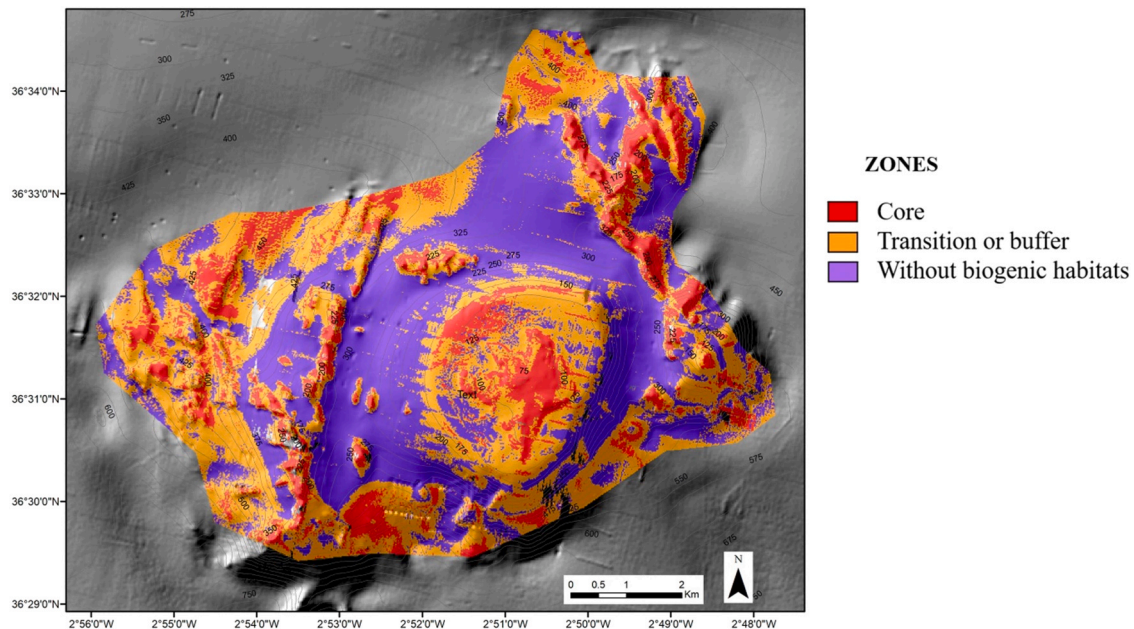
Fig. 13. Seco de los Olivos map showing the distribution of three different areas of ecological importance.

abundances [37,82,140]. The low species richness and diversity found in habitats on sandy bottoms on the summit of the central guyot (habitats 8- 'sand-pennatulids' and SBcirca- Circalittoral soft bottoms) [46] leads us to think that these habitats could be subjected to some kind of natural disturbance acting on the top of the seamount. Since the study area is a submerged zone not exposed to storms, tides or wave erosion, these shallower benthic habitats may be affected by local marine currents acting over the seamount which are feed by the three gyres that constitute the superficial circulation patterns of the Alborán Sea [146]. Nevertheless, the rest of the habitats recorded are located in the deep sea and therefore, disturbed habitats may either be the result of natural disturbances generated by currents, or be the result of bottom fishing activities -as suggested by evidence of debris found in some areas-, or may even be the result of a mixture of both.

In the case of degraded habitats, an additional uncertainty is related to the recovery of the communities once the disturbance ceases. EU countries have a mandate to implement measures to ensure the conservation of their marine ecosystems in MPAs, including recovering of degraded habitats and the ecosystem services they provide, in order to deliver the full range of conservation and socioeconomic benefits that can be derived [53]. However, it is unclear where the ecological succession of the habitats would evolve if fishing effort is limited at least in certain areas of this zone, and how long it would take to see any change. While Clark et al. [35] found little evidence of steps towards recovery of the benthic community to its pre-disturbance state on a seamount 15 years after it had been closed to trawling, Baco et al. [7], however, observed multiple signs of recovery of the deep-sea coral communities on seamounts after more than 30 years of protection. Since recovery dynamics in biotic communities in the deep sea are poorly understood [35], at the present time, spatial management is likely to be the most effective strategy to conserve and facilitate possible recovery of benthic communities of seamount [36,154]. The distribution of the different levels of habitat disturbance along with the areas characterized by favorable environmental conditions for their development provided by the models can be helpful to identify potential areas for recovery within a spatial planning for the MPA. Therefore, in addition to resistance and recovery, a third component of resilience, *reversibility* - whether the community is capable or returning to its original state following the effects of disturbances [115,130] - must be considered [35,67,68]. The greater functional redundancy that characterizes healthier stable communities [48] may make functional replacement possible because remaining individuals or colonies may favor successful local recruitment and may allow habitat reversibility, i.e., full recovery to pre-disturbance original levels after the effects of the disturbance [67,115,130]. However, high disturbed habitats largely rely on the re-colonization from neighboring areas and successful settlement [35,38,88,109] after disturbance and the reversibility is more difficult and even highly unlikely, leading the system in many cases to a new alternate stable state composed by a community different than that from the pre-disturbance state [42,68].

As a complementary tool, a zoning scheme focused on the three different areas obtained with the two thresholds used in the analysis, can serve as a guide when outlining different management zones where a variety of measures can be put into practice, from more stringent in the 'core zone' to less stringent in the 'zone without biogenic habitats'. The 'transition or buffer zone' has revealed as a suitable area for the potential recovery of benthic habitats, as indicated by the 'prevalence map' which identified it as potential area for their distribution based on the environmental conditions as well as a buffer zone around the 'core zone', since if fishermen are allowed to set their fishing gear so close to the 'core zone', their drift or the loss of equipment as well as the increase of turbidity and sedimentation rates could still damage biogenic habitats of the 'core zone', as has occurred in other areas [22,61].

CRediT authorship contribution statement

Ana de la Torriente: Conceptualization, Methodology, Software, Formal analysis, Writing – Original Draft. **Jose Manuel González-Irusta:** Conceptualization, Methodology, Software, Formal analysis. **Alberto Serrano:** Conceptualization, Methodology, Supervision, Writing – Review & Editing, Project administration. **Ricardo Aguilar:** Writing – Review & Editing. **Francisco Sánchez:** Writing – Review & Editing. **Marian Blanco:** Methodology, Investigation. **Antonio Punzón**: Conceptualization, Methodology, Software, Writing – Review & Editing, Supervision.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2021.104850.

References

[1] E. Abad, I. Preciado, A. Serrano, J. Baro, Demersal and epibenthic assemblages of trawlable grounds in the northern Alborán Sea (western Mediterranean), Sci. Mar. 71 (3) (2007) 513–524, https://doi.org/10.3989/scimar.2007.71n3513.

[2] J.I. Allen, K.R. Clarke, Effects of demersal trawling on ecosystem functioning in the North Sea: a modelling study, Mar. Ecol. Prog. Ser. 336 (2007) 63–75, https://doi.org/10.3354/meps336063.

[3] F. Althaus, A. Williams, T.A. Schlacher, R.J. Kloser, M.A. Green, B.A. Barker, N. J. Bax, P. Brodie, M.A. Schlacher-Hoenlinger, Impacts of bottom trawling on deep-coral ecosystems of seamounts are long-lasting, Mar. Ecol. Prog. Ser. 397 (2009) 279–294, https://doi.org/10.3354/meps08248.

[4] A. Altuna, A. Poliseno, 14 Taxonomy, Genetics and Biodiversity of Mediterranean Deep-Sea Corals and Cold-Water Corals, Mediterr. Cold-Water Coral.: , Present Future (2019) 121–156, https://doi.org/10.1007/978-3-319-91608-8_14.

[5] A.H. Andrews, R.P. Stone, C.C. Lundstrom, A.P. DeVogelaere, Growth rate and age determination of bamboo corals from the northeastern Pacific Ocean using refined 210Pb dating, Mar. Ecol. Prog. Ser. 397 (2009) 173–185, https://doi.org/10.3354/meps08193.

[6] E.A. Babcock, E.K. Pikitch, M. McAllister, P. Apostolaki, C. Santora, A perspective on the use of spatialized indicators for ecosystem-based fishery management through spatial zoning, ICES J. Mar. Sci. 62 (3) (2005) 469–476, https://doi.org/10.1016/j.icesjms.2005.01.010.

[7] A.R. Baco, E.B. Roark, N.B. Morgan, Amid fields of rubble, scars, and lost gear, signs of recovery observed on seamounts on 30-to 40-year time scales, Sci. Advices 5 (2019) eaaw4513, https://doi.org/10.1126/sciadv.aaw4513.

[8] J.C. Báez, R. Real, J.A. Camiñas, D. Torreblanca, C. García-Soto, Analysis of swordfish catches and by-catches in artisanal longline fisheries in the Alborán Sea (western Mediterranean Sea) during the summer season, Mar. Biodivers. Rec. 2 (2009) 1–4, https://doi.org/10.1017/S1755267209990856.

[10] E. Ballesteros, Mediterranean coralligenous assemblages: A synthesis of present knowledge, Oceanogr. Mar. Biol.: Annu. Rev. 44 (2006) 123–195.

[11] C. Barberá, C. Bordehore, J.A. Borg, M. Glémarec, J. Grall, J.M. Hall-Spencer, Ch De la Huz, E. Lanfranco, M. Lastra, P.G. Moore, J. Mora, M.E. Pita, A. A. Ramos-Espla, M. Rizzo, A. Sánchez-Mata, A. Seva, P.J. Schembri, C. Valle, Conservation and management of northeast Atlantic and Mediterranean maërl beds, Aquat. Conserv.: Mar. Freshw. Ecosyst. 13 (2003) S65–S76, https://doi.org/10.1002/aqc.569.

[12] G. Bavestrello, C. Cerrano, D. Zanzi, R. Cattaneo-Vietti, Damage by fishing activities to the Gorgonian coral *Paramuricea clavata* in the Ligurian Sea, Aquat. Conserv.: Mar. Freshw. Ecosyst. 7 (3) (1997) 253–262, https://doi.org/10.1002/(SICI)1099-0755(199709)7:3<253::AID-AQC243>3.0.CO;2-1.

[13] T. Bekkby, N. Papadopoulou, D. Fiorentino, C.J. McOwen, E. Rinde, C. Boström, M. Carreiro-Silva, C. Linares, G.S. Andersen, E.G.T. Bengil, M. Bilan, E. Cebrian, C. Cerrano, R. Danovaro, C.W. Fagerli, S. Fraschetti, K. Gagnon, C. Gambi, H. Gundersen, S. Kipson, J. Kotta, T. Morato, H. Ojaveer, E. Ramirez-Llodra, C. J. Smith, Habitat Features and Their Influence on the Restoration Potential of Marine Habitats in Europe, Front. Mar. Sci. 7 (2020) 184, https://doi.org/10.3389/fmars.2020.00184.

[14] M. Bo, S. Bava, S. Canese, M. Angiolillo, R. Cattaneo-Vietti, G. Bavestrello, Fishing impact on deep Mediterranean rocky habitats as revealed by ROV investigation, Biol. Conserv. 171 (2014) 167–176, https://doi.org/10.1016/j.biocon.2014.01.011.

[17] S.G. Bolam, J. Eggleton, J. Barry, Spatial variability of macrofaunal traits across the Greater North Sea, J. Sea Res. 163 (2020), 101923.

[18] Bordehore, C., Borg, J.A., Lanfranco, E., Ramos-Esplá, A.A., Rizzo, M., Schembri, P., 2000. Trawling as a major threat to Mediterranean maërl beds, presented at the First Mediterranean Symposium on Marine Vegetation, Regional Activity Centre for Specially Protected Areas [UNEP Mediterranean Action Plan], Ajaccio, Corsica, France 2–3 October 2000.

[20] Borg, J.A., Lanfranco, E., Mifsud, J.R., Rizzom M., Schembri, P.J., 1999. Does fishing have an impact on Maltese maerl grounds? In: BIOMAERL team (1999) Final Report (in 2 vols), BIOMAERL project (Coordinator: P.G. Moore, University Marine Biological Station Millport, Scotland), EC Contract No. MAS3-CT95–0020, pp 1–541, 542–973 + appendix.

[21] D. Bosence, J. Wilson, Maërl growth, carbonate production rates and accumulation rates in the northeast Atlantic, Aquat. Conserv.: Mar. Freshw. Ecosyst. 13 (2003) S21–S31, https://doi.org/10.1002/aqc.565.

[22] Breeze, H., Davis, D.S., Butler, M., Kostylev, V., 1997. Distribution and status of deep-sea corals off Nova Scotia. Marine Issues Committee Special Publication Number 1. Ecology Action Centre. Halifax, Canada.

[23] J. Bremner, S.I. Rogers, C.L.J. Frid, Assessing functional diversity in marine benthic ecosystems: a comparison of approaches, Mar. Ecol. Prog. Ser. 254 (2003) 11–25, https://doi.org/10.3354/meps254011.

[26] L. Buhl-Mortensen, P. Buhl-Mortensen, M.F.J. Dolan, B. Holte, The MAREANO programme – A full coverage mapping of the Norwegian off-shore benthic environment and fauna, Mar. Biol. Res. 11 (1) (2015) 4–17, https://doi.org/10.1080/17451000.2014.952312.

[28] M. Carreiro-Silva, A. Braga-Henriques, Í. Sampaio, V. de Matos, F.M. Porteiro, O. Ocana, *Isozoanthus primnoidus*, a new species of zoanthid (Cnidaria: Zoantharia) associated with the gorgonian *Callogorgia verticillate* (Cnidaria: Alcyonacea), ICES J. Mar. Sci. 68 (2011) 408–415, https://doi.org/10.1093/icesjms/fsq073.

[29] M. Carreiro-Silva, A.H. Andrews, A. Braga-Henriques, V. De Matos, F.M. Porteiro, R.S. Santos, Variability in growth rates of long-lived black coral *Leiopathes* sp. from the Azores, Mar. Ecol. Prog. Ser. 473 (2013) 189–199, https://doi.org/10.3354/meps10052.

[30] J.E. Cartes, C. Lo Iacono, V. Mamouridis, C. López-Pérez, P. Rodríguez, Geomorphological, trophic and human influences on the bamboo coral *Isidella elongata* assemblages in the deep Mediterranean: To what extent does Isidella form habitat for fish and invertebrates? Deep Sea Res. Part I: Oceanogr. Res. Pap. 76 (2013) 52–65, https://doi.org/10.1016/j.dsr.2013.01.006.

[32] R. Chuenpagdee, L.E. Morgan, S.M. Maxwell, E.A. Norse, D. Pauly, Shifting gears: assessing collateral impacts of fishing methods in US waters, Front. Ecol. Environ. 1 (2003) 517–524, https://doi.org/10.1890/1540-9295(2003)001[0517:SGACIO]2.0.CO;2.

[33] Clark, M.R., Koslow, J.A., 2007. Impacts of fisheries on seamounts. In: Seamounts: Ecology, Fisheries, and Conservation, ed.T.J. Pitcher, T. Morato, P.J. B. Hart, M.R. Clark, N. Haggan & R.S. Santos, pp. 413–441. Blackwell Fisheries and Aquatic Resources Series 12. Oxford, UK: Blackwell Publishing. ⟨DOI: https://doi.org/10.1002/9780470691953.ch19⟩.

[34] M.R. Clark, F. Althaus, T.A. Schlacher, A. Williams, D.A. Bowden, A.A. Rowden, The impacts of deep-sea fisheries on benthic communities: a review, ICES J. Mar. Sci. 73 (Supplement 1) (2016) i51–i69, https://doi.org/10.1093/icesjms/fsv123.

[35] M.R. Clark, D.A. Bowden, A.A. Rowden, R. Stewart, Little evidence of benthic community resilience to bottom trawling on seamounts after 15 years, Front. Mar. Sci. 6 (2019) 63, https://doi.org/10.3389/fmars.2019.00063.

[36] M.R. Clark, M.R. Dunn, Spatial management of deep-sea seamount fisheries: balancing sustainable exploitation and habitat conservation, Environ. Conserv. 39 (2012) 204–214, https://doi.org/10.1017/S0376892912000021.

[37] J.S. Collie, S.J. Hall, M.J. Kaiser, I.R. Poiner, A quantitative analysis of fishing impacts on shelf-sea benthos, J. Anim. Ecol. 69 (2000) 785–798, https://doi.org/10.1046/j.1365-2656.2000.00434.x.

[38] J.H. Connell, M.J. Keough, Disturbance and patch dynamics of subtidal marine animals on hard substrata. The Ecology of Natural Disturbance and Patch Dynamics, Academic Press,, Orlando, FL, 1985, pp. 125–151, https://doi.org/10.1016/B978-0-12-554520-4.50013-7.

[39] G. Corbera, C. Lo Iacono, E. Gràcia, J. Grinyó, M. Pierdomenico, V.A.I. Huvenne, R. Aguilar, J.M. Gili, Ecological characterization of a Mediterranean cold-water coral reef: Cabliers Coral Mound Province (Alborán Sea, western Mediterranean), Prog. Oceanogr. 175 (2019) 245–262, https://doi.org/10.1016/j.pocean.2019.04.010.

[40] S. de Juan, S.F. Thrush, M. Demestre, Functional changes as indicators of trawling disturbance on a benthic community located in a fishing ground (NW Mediterranean Sea), Mar. Ecol. Prog. Ser. 334 (2007) 117–129, https://doi.org/10.3354/meps334117.

[42] S. de Juan, M. Demestre, A Trawl Disturbance Indicator to quantify large scale fishing impact on benthic ecosystems, Ecol. Indic. 18 (2012) 183–190, https://doi.org/10.1016/j.ecolind.2011.11.020.

[43] A. De la Torriente, R. Aguilar, A. Serrano, S. García, L.M. Fernández, M. García, A. Punzón, J.M. Arcos, R. Sagarminaga, Sur de Almería - Seco de los Olivos. Proyecto LIFE+ INDEMARES. Ed. Fundación Biodiversidad del Ministerio de, Agric., Aliment. Y. Medio Ambient. 2014 (2014) 102.

[44] A. De la Torriente, A. Serrano, L.M. Fernández-Salas, M. García, R. Aguilar, Identifying epibenthic habitats on the Seco de los Olivos Seamount: Species assemblages and environmental characteristics, Deep Sea Res. Part I 135 (2018) 9–22, https://doi.org/10.1016/j.dsr.2018.03.015.

[45] A. De la Torriente, J.M. González-Irusta, R. Aguilar, L.M. Fernández-Salas, A. Punzón, A. Serrano, Benthic habitat modelling and mapping as a conservation tool for marine protected areas: A seamount in the western Mediterranean, Aquat. Conserv.: Mar. Freshw. Ecosyst. 29 (5) (2019) 1–19, https://doi.org/10.1002/aqc.3075.

[46] A. De la Torriente, R. Aguilar, J.M. González-Irusta, M. Blanco, A. Serrano, Habitat forming species explain taxonomic and functional diversities in a

Mediterranean seamount, Ecol. Indic. 118 (2020), 106747, https://doi.org/10.1016/j.ecolind.2020.106747.

[47] De la Torriente, Identification, distribution, taxonomic and functional composition of the benthic habitats covering the Seco de los Olivos Seamount and its application to management and conservation (PhD Thesis. Facultad de Ciencias del Mar y Ambientales), Universidad de Cádiz,, 2021, p. 365 (PhD Thesis. Facultad de Ciencias del Mar y Ambientales).

[48] S. Díaz, M. Cabido, Vive la différence: plant functional diversity matters to ecosystem processes, Trends Ecol. Evol. 16 (11) (2001) 646–655, https://doi.org/10.1016/S0169-5347(01)02283-2.

[49] G. D'Onghia, F. Mastrototaro, A. Matarrese, C.Y. Politou, Ch Mytilineou, Biodiversity of the upper slope demersal community in the eastern Mediterranean: preliminary comparison between two areas with and without trawl fishing, J. Northwest Atl. Fish. Sci. 31 (2003) 263–273, https://doi.org/10.2960/J.v31.a20.

[51] P. Durán-Muñoz, F.J. Murillo, M. Sayago-Gil, A. Serrano, M. Laporta, I. Otero, C. Gómez, Effects of deep-sea bottom longlining on the Hatton Bank fish communities and benthic ecosystem, north-east Atlantic, J. Mar. Biol. Assoc. U. Kingd. 91 (4) (2011) 939–952, https://doi.org/10.1017/S0025315410001773.

[52] Elliott, S.A.M., Arroyo, N.L., Safi, G., Ostle, C., Guérin, L., McQuatters-Gollop, A., Aubert, A., Artigas, F., Budria, A., Rombouts, I., Pesch, R., Schmitt, P., Vina-Herbon, C., Meakins, B., González-Irusta, J.M., Preciado, I., López-López, L., Punzón, A., Torriente, A., Serrano, A., Haraldsson, M., Capuzzo, E., Claquin, P., Kromkamp, J., Niquil, N., Judd, A., Padegimas, B., Corcoran, E., 2017. Proposed approaches for indicator integration. EcApRHA Deliverable WP 4.1., 46pp, ⟨https://www.ospar.org/work-areas/bdc/ecaprha/reports⟩.

[53] S.A.M. Elliott, L. Guérin, R. Pesch, P. Schmitt, B. Meakins, C. Vina-Herbon, J. M. González-Irusta, A. De la Torriente, A. Serrano, Integrating benthic habitat indicators: Working towards an ecosystem approach, Mar. Policy 90 (2018) 88–94, https://doi.org/10.1016/j.marpol.2018.01.003.

[54] Ewing, G.P., Kilpatrick, R. 2014. Estimating the gear footprint of demersal trawl and longline fishing gears used in the Heard Island and McDonald Islands fisheries. In Demersal fishing interactions with marine benthos in the Australian EEZ of the Southern Ocean: An assessment of the vulnerability of benthic habitats to impact by demersal gears Final Report FRDC Project 2006/042. Ed. by D.C. Welsford, G.P. Ewing, A.J. Constable, T. Hibberd, and R. Kilpatrick. The Department of the Environment, Australian Antarctic Division and the Fisheries Research and Development Corporation, Hobart, Tasmania, Australia, 265 pp.

[55] European Commission, Commission Implementing Regulation (EU) No 404/2011 of 8 April 2011 laying down detailed rules for the implementation of Council Regulation (EC) No 1224/2009 establishing a Community control system for ensuring compliance with the rules of the Common Fisheries Policy, Off. J. Eur. Union L 112 (2011) 1–153.

[56] M.C. Fabri, L. Pedel, L. Beuck, F. Galgani, D. Hebbeln, A. Freiwald, Megafauna of vulnerable marine ecosystems in French Mediterranean submarine canyons: Spatial distribution and anthropogenic impacts, Deep Sea Res. Part II-Top. Stud. Oceanogr. 104 (2014) 184–207, https://doi.org/10.1016/j.dsr2.2013.06.016.

[59] F. Ferrigno, L. Appolloni, G.F. Russo, R. Sandulli, Impact of fishing activities on different coralligenous assemblages of Gulf of Naples (Italy), 2018, J. Mar. Biol. Assoc. U. Kingd. 98 (1) (2018) 41–50, https://doi.org/10.1017/S0025315417001096.

[60] G. Försterra, V. Häussermann, J. Laudien, Animal Forests in the Chilean Fjords: Discoveries, Perspectives and Threats in Shallow and Deep waters, in: S. Rossi, L. Bramanti, A. Gori, C. Orejas Saco del Valle (Eds.), Marine Animal Forests, Springer, Cham, 2016, https://doi.org/10.1007/978-3-319-17001-5_3-1.

[61] J.H. Fossa, P.B. Mortensen, D.M. Furevik, The deep-water coral *Lophelia pertusa* in Norwegian waters: distribution and fishery impacts, Hydrobiologia 471 (1) (2002) 1–12, https://doi.org/10.1023/A:1016504430684.

[62] E.A. Freeman, G.G. Moisen, A comparison of the performance of threshold criteria for binary classification in terms of predicted prevalence and kappa, Ecol. Model. 217 (1–2) (2008) 48–58, https://doi.org/10.1016/j.ecolmodel.2008.05.015.

[64] A. García-Alegre, F. Sánchez, M. Gómez-Ballesteros, H. Hilmar, A. Serrano, S. Parra, Modelling and mapping the local distribution of representative species on the Le Danois Bank, El Cachucho Marine Protected Area (Cantabrian Sea), Deep Sea Res. Part II: Top. Stud. Oceanogr. 106 (2014) 151–164, https://doi.org/10.1016/j.dsr2.2013.12.012.

[65] GFCM, 2018. Report of the second meeting of the Working Group on Vulnerable Marine Ecosystems (WGVME), General Fisheries Commission for the Mediterranean, Roma, Italy, 57 pp.

[67] S. Gollner, S. Kaiser, L. Menzel, D.O.B. Jones, A. Brown, N.C. Mestre, D. Oevelen, Van, L. Menot, A. Colaco, M. Canals, D. Cuvelier, J.M. Durden, A. Gebruk, G. A. Egho, M. Haeckel, Y. Marcon, L. Mevenkamp, T. Morato, C.K. Pham, A. Purser, A. Sanchez-vidal, A. Vanreusel, A. Vink, P. Martinez, D. van Oevelen, L. Menot, A. Colaʃgo, M. Canals, D. Cuvelier, J.M. Durden, A. Gebruk, G.A. Egho, M. Haeckel, Y. Marcon, L. Mevenkamp, T. Morato, C.K. Pham, A. Purser, Resilience of benthic deep-sea fauna to mining activities, Mar. Environ. Res. 129 (2017) 76–101, https://doi.org/10.1016/j.marenvres.2017.04.010.

[68] S.L. Goode, A.A. Rowden, D.A. Bowden, M.R. Clark, Resilience of seamount benthic communities to trawling disturbance, Mar. Environ. Res. 161 (2020), 105086, https://doi.org/10.1016/j.marenvres.2020.105086.

[69] J.M. González-Irusta, A. De la Torriente, A. Punzón, M. Blanco, A. Serrano, Determining and mapping species sensitivity to trawling impacts: the BEnthos Sensitivity Index to Trawling Operations (BESITO), ICES J. Mar. Sci. 75 (5) (2018) 1720–1721, https://doi.org/10.1093/icesjms/fsy030.

[70] J.S. Gray, P. Dayton, S. Thrush, M.J. Kaiser, On effects of trawling, benthos and sampling design, Mar. Pollut. Bull. 52 (8) (2006) 840–843, https://doi.org/10.1016/j.marpolbul.2006.07.003.

[71] J. Grinyó, C. Lo Iacono, M. Pierdomenico, S. Conlon, G. Corbera, E. Gràcia, Evidences of human impacts on megabenthic assemblages of bathyal sediments in the Alborán Sea (western Mediterranean), Deep Sea Res. Part I: Oceanogr. Res. Pap. 165 (2020), 103369, https://doi.org/10.1016/j.dsr.2020.103369.

[72] L.H. Gunderson, Ecological resilience- in theory and application, Annu. Rev. Ecol. Syst. 31 (2000) 425–439, https://doi.org/10.1146/annurev.ecolsys.31.1.425.

[73] J.M. Hall-Spencer, P.G. Moore, Scallop dredging has profound, long-term impacts on maërl habitats, ICES J. Mar. Sci. 57 (5) (2000) 1407–1415, https://doi.org/10.1006/jmsc.2000.0918.

[77] N. Hintzen, F. Bastardie, D. Beare, G. Piet, C. Ulrich, N. Deporte, J. Egekvist, H. Degel, VMStools: Open-source software for the processing, analysis and visualisation of fisheries logbook and VMS data, Fish. Res. 115–116 (2012) 31–43, https://doi.org/10.1016/j.fishres.2011.11.007.

[78] J.G. Hiddink, S. Jennings, M.J. Kaiser, A.M. Queirós, D.E. Duplisea, G. Piet, Cumulative Impacts of Seabed Trawl Disturbance on Benthic Biomass, Production, and Species Richness in Different Habitats, Can. J. Fish. Aquat. Sci. 63 (4) (2006) 721–736, https://doi.org/10.1139/f05-266.

[81] S. Kark, Effects of Ecotones on Biodiversity. Reference Module in Life Sciences, Elsevier,, 2017, https://doi.org/10.1016/B978-0-12-809633-8.02290-1.

[82] M.J. Kaiser, A.S. Hill, K. Ramsay, B.E. Spencer, A.R. Brand, L.O. Veale, K. Prudden, E.I.S. Rees, B.W. Munday, N. Ball, S.J. Hawkins, Benthic disturbance by fishing gear in the Irish Sea: a comparison of beam trawling and scallop dredging, Aquat. Conserv.: Mar. Freshw. Ecosyst. 6 (1996) 269–285, https://doi.org/10.1002/(SICI)1099-0755(199612)6:4<269::AID-AQC202>3.0.CO;2-C.

[83] M.J. Kaiser, J.S. Collie, S.J. Hall, S. Jennings, I.R. Poiner, Modification of marine habitats by trawling activities: prognosis and solutions, Fish Fish 3 (2002) 114–136, https://doi.org/10.1046/j.1467-2979.2002.00079.x.

[84] A.J. Kenny, C. Jenkins, D. Wood, S.G. Bolam, P. Mitchell, C. Scougal, A. Judd, Assessing cumulative human activities, pressures, and impacts on North Sea benthic habitats using a biological traits approach, ICES J. Mar. Sci. 75 (3) (2018) 1080–1092.

[85] K.M. Kleisner, M. Coll, C.P. Lynam, A. Bundy, L. Shannon, Y.J. Shin, J.L. Boldt, M. F. Borges, I. Diallo, C. Fox, D. Gascuel, J.J. Heymans, M.J. Juan-Jorda, D. Jouffre, S.I. Large, K.N. Marshall, H. Ojaveer, Ch Piroddi, J. Tam, M.A. Torres, M. Travers-Trolet, K. Tsagarakis, G.I. Van Der Meeren, S. Zador, Evaluating changes in marine communities that provide ecosystem services through comparative assessments of community indicators, Ecosyst. Serv. 16 (2015) 413–429, https://doi.org/10.1016/j.ecoser.2015.02.002.

[86] W.H. Kruskal, W.A. Wallis, Use of ranks in one-criterion variance analysis, J. Am. Stat. Assoc. 47 (260) (1952) 583–621, https://doi.org/10.2307/2280779.

[87] W.E. Kunin, Biodiversity at the edge: A test of the importance of spatial "mass effects" in the Rothamsted Park Grass experiments, Proc. Natl. Acad. Sci. Vol. 95 (1) (1998) 207–212, https://doi.org/10.1073/pnas.95.1.207.

[88] M. Lacharité, A. Metaxas, Early life history of deep-water gorgonian corals may limit their abundance, PLOS ONE 8 (6) (2013), e65394, https://doi.org/10.1371/journal.pone.0065394.

[109] G.I. Lambert, S. Jennings, M.J. Kaiser, T.W. Davies, J.G. Hiddink, Quantifying recovery rates and resilience of seabed habitats impacted by bottom fishing, J. Appl. Ecol. 51 (2014) 1326–1336, https://doi.org/10.1111/1365-2664.12277.

[110] J. Lee, A.B. South, S. Jennings, Developing reliable, repeatable, and accessible methods to provide high-resolution estimates of fishing-effort distributions from vessel monitoring system (VMS) data, ICES J. Mar. Sci. 67 (6) (2010) 1260–1271, https://doi.org/10.1093/icesjms/fsq010.

[111] J.S. Link, Ecosystem-based fisheries management: Confronting tradeoffs, Cambridge University Press,, Cambridge, UK, 2010, p. 207, https://doi.org/10.1017/CBO9780511667091.

[112] C. Llompart, Braquiópodos del Banco de Chella (Mar de Alborán, Mediterráneo Occidental), Acta Geológica Hispánica v 23 (1988) 311–319.

[113] C. Lo Iacono, E. Gràcia, R. Bartolomé, E. Coiras, J.J. Dañobeitia, J. Acosta, Habitats of the Chella Bank, Eastern Alborán Sea (Western Mediterranean), in: P.T. Harris, E.K. Baker (Eds.), Seafloor Geomorphology as Benthic Habitat, Elsevier, London, 2012, pp. 681–690, https://doi.org/10.1016/B978-0-12-385140-6.00049-9.

[114] C. Lo Iacono, J. Grinyó, S. Conlon, M. Lafosse, A. Rabaute, M. Pierdomenico, H. Perea, E. d'Acremont, E. Gràcia, Near-pristine benthic habitats on the Francesc Pagès Bank, Alborán Sea, western Mediterranean, chapter 5, in: P. T. Harris, E. Baker (Eds.), Seafloor Geomorphology as Benthic Habitat, (second edition)., Elsevier, 2020, pp. 889–901, https://doi.org/10.1016/B978-0-12-814960-7.00055-5. chapter 5.

[115] H.K. Lotze, M. Coll, A.M. Magera, C. Ward-Paige, L. Airoldi, Recovery of marine animal populations and ecosystems, Trends Ecol. Evol. 26 (11) (2011) 595–605, https://doi.org/10.1016/j.tree.2011.07.008.

[116] D.S. MacDonald, M. Little, N. Clare Eno, K. Hiscock, Disturbance of benthic species by fishing activities: a sensitivity index, Aquat. Conserv.: Mar. Freshw. Ecosyst. 6 (4) (1996) 257–268, https://doi.org/10.1002/(SICI)1099-0755(199612)6:4<257::AID-AQC194>3.0.CO;2-7.

[117] MarLIN, 2006. BIOTIC - Biological Traits Information Catalogue. Marine Life Information Network. Plymouth: Marine Biological Association of the United Kingdom. [06/08/2019] Available from < www.marlin.ac.uk/biotic >.

[118] F. Mastrototaro, P. Maiorano, A. Vertino, D. Battista, A. Indennidate, A. Savini, A. Tursi, G. D'Onghila, A facies of *Kophobelemnon* (Cnidaria, Octocorallia) from

Santa Maria di Leuca coral province (Mediterranean Sea), Mar. Ecol. 34 (3) (2013) 313–320, https://doi.org/10.1111/maec.12017.

[119] F. Mastrototaro, G. Chimienti, J. Acosta, J. Blanco, S. García, J. Rivera, R. Aguilar, *Isidella elongata* (Cnidaria: Alcyonacea) facies in the western Mediterranean Sea: visual surveys and descriptions of its ecological role, Eur. Zool. J. 84 (1) (2017) 209–225, https://doi.org/10.1080/24750263.2017.1315745.

[120] F. Maynou, J.E. Cartes, Effects of trawling on fish and invertebrates from deep-sea coral facies of *Isidella elongata* in the western Mediterranean, J. Mar. Biol. Assoc. U. Kingd. 92 (7) (2011) 1501–1507, https://doi.org/10.1017/S0025315411001603.

[121] M. Miatta, A.E. Bates, P.V.R. Snelgrove, Incorporating biological traits into conservation strategies, Annu. Rev. Mar. Sci. 13 (2021) 421–443, https://doi.org/10.1146/annurev-marine-032320-094121.

[122] J. Moranta, C. Barberá, M. Druet, N. Zaragoza (Eds.), Caracterización ecológica de la plataforma continental (50–100m) del canal de Menorca, Instituto Español de Oceanografía-Centre Oceanogràfic de Balears, Fundación Biodiversidad, Palma, 2014.

[123] T. Morato, R. Watson, T.J. Pitcher, D. Pauly, Fishing down the deep, Fish Fish 7 (1) (2006) 24–34, https://doi.org/10.1111/j.1467-2979.2006.00205.x.

[124] P.B. Mortensen, L. Buhl-Mortensen, D.C. Gordon Jr., Effects of fisheries on deepwater gorgonian corals in the Northeast Channel, 41, American Fisheries Society Symposium,, Nova Scotia, 2005, pp. 369–382.

[125] F.J. Murillo, P. Durán-Muñoz, J. Cristobo, P. Ríoz, C. Gónzalez, E. Kenchington, A. Serrano, Deep-sea sponge grounds of the Flemish Cap, Flemish Pass and the Grand Banks of Newfoundland (Northwest Atlantic Ocean): Distribution and species composition, Mar. Biol. Res. 8 (9) (2012) 842–854, https://doi.org/10.1080/17451000.2012.682583.

[126] S. Naeem, Species redundancy and ecosystem reliability, Conserv. Biol. 12 (1) (1998) 39–45, https://doi.org/10.1111/j.1523-1739.1998.96379.x.

[127] C. Orejas, A. Gori, C. Lo Iacono, P. Puig, J.M. Gili, M.R.T. Dale, Cold-water corals in the Cap de Creus canyon, northwestern Mediterranean: spatial distribution, density and anthropogenic impact, Mar. Ecol. Prog. 397 (2009) 37–51, https://doi.org/10.3354/meps08314.

[128] F. Ordines, M. Ramón, J. Rivera, C. Rodríguez-Prieto, M.T. Farriols, B. Guijarro, C. Pasqual, E. Massutí, Why long term trawled red algae beds off Balearic Islands (western Mediterranean) still persist? Reg. Stud. Mar. Sci. 15 (2017) 39–49, https://doi.org/10.1016/j.rsma.2017.07.005.

[130] S.R. Palumbi, K.L. McLeod, D. Grünbaum, Ecosystems in Action: Lessons from Marine Ecology about Recovery, Resistance, and Reversibility, Bioscience 58 (1) (2008) 33–42, https://doi.org/10.1641/b580108.

[131] S.J. Parker, D.A. Bowden, Identifying taxonomic groups vulnerable to bottom longline fishing gear in the Ross Sea region, CCAMLR Sci. 17 (2010) 105–127.

[133] C.K. Pham, H. Diogo, G. Menezes, F. Porteiro, A. Braga-Henriques, F. Vendeperre, T. Morato, Deep-water longline fishing has reduced impact on Vulnerable Marine Ecosystems, Sci. Rep. 4 (2014) 4837, https://doi.org/10.1038/srep04837.

[134] M. Pierdomenico, T. Russo, S. Ambroso, A. Gori, E. Martorelli, L. D'Andrea, J. M. Gili, F.L. Chiocci, Effects of trawling activity on the bamboo-coral *Isidella elongata* and the sea pen *Funiculina quadrangularis* along the Gioia Canyon (Western Mediterranean, southern Tyrrhenian Sea), Prog. Oceanogr. 169 (2018) 214–226, https://doi.org/10.1016/j.pocean.2018.02.019.

[135] E.K. Pikitch, C. Santora, E.A. Babcock, A. Bakun, R. Bonfil, D.O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E.D. Houde, J. Link, P. A. Livingston, M. Mangel, M.K. McAllister, J. Pope, K.J. Sainsbury, Ecosystem-Based Fishery Management, Science 305 (5682) (2004) 346–347, https://doi.org/10.1126/science.1098222.

[136] S.L. Pimm, The complexity and stability of ecosystems, Nature 307 (1984) 321–326, https://doi.org/10.1038/307321a0.

[138] P.K. Probert, D.G. McKnight, S.L. Grove, Benthic invertebrate bycatch from a deep-water trawl fishery, Chatham Rise, New Zealand, Aquat. Conserv.: Mar. Freshw. Ecosyst. 7 (1) (1997) 27–40, https://doi.org/10.1002/(SICI)1099-0755(199703)7:1<27::AID-AQC214>3.0.CO;2-9.

[139] A. Pusceddu, S. Bianchelli, J. Martín, P. Puig, A. Palanques, P. Masqué, R. Danovaro, Chronic and intensive bottom trawling impairs deep-sea biodiversity and ecosystem functioning, Proc. Natl. Acad. Sci. 111 (24) (2014) 8861–8866, https://doi.org/10.1073/pnas.1405454111.

[140] A.M. Queirós, J.G. Hiddink, M.J. Kaiser, H. Hinz, Effects of chronic bottom trawling disturbance on benthic biomass, production and size spectra in different habitats, J. Exp. Mar. Biol. Ecol. 335 (1) (2006) 91–103, https://doi.org/10.1016/j.jembe.2006.03.001.

[141] R Development Core Team, 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/.

[143] B. Ramiro-Sánchez, J.M. González-Irusta, L.A. Henry, J. Cleland, I. Yeo, J. R. Xavier, M. Carreiro-Silva, Í. Sampaio, J. Spearman, L. Victorero, C.G. Messing, G. Kazanidis, J.M. Roberts, B. Murton, Characterization and Mapping of a Deep-Sea Sponge Ground on the Tropic Seamount (Northeast Tropical Atlantic): Implications for Spatial Management in the High Seas, Front. Mar. Sci. 6 (2019) 278, https://doi.org/10.3389/fmars.2019.00278.

[144] J.K. Reed, Deep-water *Oculina* coral reefs of Florida: biology, impacts, and management, Hydrobiologia 471 (1) (2002) 43–55, https://doi.org/10.1023/A:1016588901551.

[145] S. Reizopoulou, N. Simboura, E. Barbone, F. Aleffi, A. Basset, A. Nicolaidou, Biodiversity in transitional waters: steeper ecotone, lower diversity, Mar. Ecol. 35 (s1) (2014) 78–84, https://doi.org/10.1111/maec.12121.

[146] L. Renault, T. Oguz, A. Pascual, G. Vizoso, J. Tintore, Surface circulation in the Alborán Sea (western Mediterranean) inferred from remotely sensed data, J. Geophys. Res. 117 (C08) (2012) 009, https://doi.org/10.1029/2011JC007659.

[148] A. Rodríguez-Basalo, F. Sánchez, A. Punzón, M. Gómez-Ballesteros, Updating the Master Management Plan for El Cachucho MPA (Cantabrian Sea) using a spatial planning approach, Cont. Shelf Res. 184 (2019) 54–65, https://doi.org/10.1016/j.csr.2019.06.010.

[149] S. Rossi, L. Bramanti, A. Gori, C. Orejas, in: S. Rossi, L. Bramanti, A. Gori, C. Orejas (Eds.), An Overview of the Animal Forests of the World. In: Marine Animal Forests: the ecology of benthic biodiversity hotspots, Springer, Germany, 2017, pp. 1–28.

[150] A.A. Rowden, T.R.R. Pearman, D.A. Bowden, O.F. Anderson, M.R. Clark, Determining coral density thresholds for identifying structurally complex Vulnerable Marine Ecosystems in the deep sea, Front. Mar. Sci. 7 (2020) 95, https://doi.org/10.3389/fmars.2020.00095.

[152] Í. Sampaio, A. Braga-Henriques, C. Pham, O. Ocaña, V. De Matos, T. Morato, Cold-water corals landed by bottom longline fisheries in the Azores (north-eastern Atlantic), J. Mar. Biol. Assoc. U. Kingd. 92 (7) (2012) 1547–1555, https://doi.org/10.1017/S0025315412000045.

[153] F. Sardà, A. Calafat, M.M. Flexas, A. Tselepides, M. Canals, M. Espino, A. Tursi, An introduction to Mediterranean deep-sea biology, Sci. Mar. 68 (Suppl. 3) (2004) 7–38.

[154] T.A. Schlacher, A.R. Baco, A.A. Rowden, T.D. O'Hara, M.R. Clark, C. Kelley, J. F. Dower, Seamount benthos in a cobalt-rich crust region of the central Pacific: conservation challenges for future seabed mining, Divers. Distrib. 20 (5) (2014) 491e502–502, https://doi.org/10.1111/ddi.12142.

[155] A. Serrano, J.M. González-Irusta, A. Punzón, A. García-Alegre, A. Lourido, P. Ríos, M. Blanco, M. Gómez-Ballesteros, M. Druet, J. Cristobo, J.E. Cartes, Deep-sea benthic habitats modelling and mapping in a NE Atlantic seamount (Galicia Bank), Deep Sea Res. Part I 126 (2017) 115–127, https://doi.org/10.1016/j.dsr.2017.06.003.

[158] SPA/RAC–UN Environment/MAP- OCEANA, 2017. Guidelines for inventorying and monitoring of dark habitats in the Mediterranean Sea. By Vasilis GEROVASILEIOU, Ricardo AGUILAR, Pilar MARÍN. Ed. SPA/RAC -Deep Sea Lebanon Project, Tunis: 40 pp + Annexes.

[159] S.F. Thrush, P.K. Dayton, What Can Ecology Contribute to Ecosystem-Based Management? Annu. Rev. Mar. Sci. 2 (2010) 419–441, https://doi.org/10.1146/annurev-marine-120308-081129.

[160] H.M. Tillin, J.G. Hiddink, S. Jennings, M.J. Kaiser, Chronic bottom trawling alters the functional composition of benthic invertebrate communities on a sea-basin scale, Mar. Ecol. Prog. Ser. 318 (2006) 31–45, https://doi.org/10.3354/meps318031.

[161] UNEP, 2019. Draft Updated Reference List of Marine Habitat Types for the Selection of Sites to be included in the National Inventories of Natural Sites of Conservation Interest in the Mediterranean. United Nations Environment Programme Mediterranean Action Plan- 7th Meeting of the Ecosystem Approach Coordination Group, Athens - UNEP/MED WG.467/14.

[162] P.D. van Denderen, S.G. Bolam, J.G. Hiddink, S. Jennings, A. Kenny, A. D. Rijnsdorp, T. Van Kooten, Similar effects of bottom trawling and natural disturbance on composition and function of benthic communities across habitats, Mar. Ecol. Prog. Ser. 541 (2015) 31–43, https://doi.org/10.3354/meps11550.

[163] A.D.T. Vierod, J.M. Guinotte, A.J. Davies, Predicting the distribution of vulnerable marine ecosystems in the deep-sea using presence-background models, Deep Sea Res. Part II: Top. Stud. Oceanogr. 99 (2014) 6–18, https://doi.org/10.1016/j.dsr2.2013.06.010.

[164] L. Watling, The Global Destruction of Bottom Habitats by Mobile Fishing Gear. Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity, Island Press,, Washington, DC, 2005, pp. 198–210.

[165] Welsford, D., R. Kilpatrick. 2008. Estimating the swept area of demersal longlines based on in situ video footage. Document WG-FSA08/58. CCAMLR, Hobart, Australia.

[166] B. Williams, M.J. Risk, S.W. Ross, K.J. Sulak, Stable isotope data from deep water antipatharians: 400-year records from the southeastern coast of the United States of America, Bull. Mar. Sci. 81 (3) (2007) 437–447.

[167] B. Worm, E.B. Barbier, N. Beaumont, J.E. Duffy, C. Folke, B.S. Halpern, J.B. C. Jackson, H.K. Lotze, F. Micheli, S.R. Palumbi, E. Sala, K.A. Selkoe, J. J. Stachowicz, R. Watson, Impacts of biodiversity loss on ocean ecosystem services, Science 314 (5800) (2006) 787–790, https://doi.org/10.1126/science.1132294.

[168] WoRMS Editorial Board (2020). World Register of Marine Species. Available from ⟨http://www.marinespecies.org⟩ at VLIZ. Accessed 2020–09-08. ⟨DOI: https://doi.org/10.14284/170⟩.