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Coexistence of megabenthic assemblages and artisanal fishers: The case of Cap de Creus Marine Protected Area (North-Western Mediterranean Sea)

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ABSTRACT

Artisanal fisheries, although considered less harmful, can still endanger marine ecosystems, especially in areas with long-standing tradition. In Cap de Creus, where artisanal fisheries has likely occurred for centuries, the status of benthic communities in fishing grounds was poorly understood. Through collaboration with local fishers, the benthic assemblages in three artisanal fishing grounds within Cap de Creus Marine Protected Area (MPA) were studied. Using video transects recorded by a remotely operated vehicle (ROV), the diversity and distribution of species were analysed in relation to substrate type, slope, and depth. The study also assessed the impacts on these communities by examining marine litter, lost fishing gear, and the condition of gorgonian populations. The findings identified three megabenthic assemblages and revealed higher fishing pressure and impact in the Maça d'Oros area, likely due to multiple fishing guilds converging. However, the study demonstrated lower impact in MPAs compared to unprotected Mediterranean areas, highlighting the importance of coastal management.

1. Introduction

Benthic communities comprise a wide variety of habitats fundamental to aquatic ecosystems, playing a major role in ecological processes (Crespo et al., 2020; Snelgrove, 1997). These communities, especially in coastal areas, are crucial for benthic-pelagic coupling processes, important for nutrient cycling and energy transfer in food webs (Griffiths et al., 2017). Additionally, they provide habitat, refuge and nursery grounds to a wide range of associated species, some of which of commercial value (Henseler et al., 2019; Kritzer et al., 2016; Rufino et al., 2017). World benthic ecosystems are being degraded to different extents by the detrimental effects caused by climate change, nutrient loading and fishing practices (Griffiths et al., 2017; Lotze et al., 2006). In the Mediterranean the degraddation of benthic ecosystems appears to occur faster than in other temperate areas of the world (Garrabou et al., 2022). In fact, according to the recent Mediterranean IUCN Red List evaluations, 25% of the Mediterranean anthozoans are estimated to be threatened with extinction (Critically Endangered (CR), Endangered (EN), or Vulnerable (VU)), including species like *Paramuricea clavata* (VU) and *Corallium rubrum* (EN) in rocky habitats, or *Pennatula rubra* (VU) and *Pteroides spinosum* (VU) in soft bottoms, which play important structuring roles in NW Mediterranean littoral and inner shelf habitats (Otero et al., 2017). Their classification as endangered is largely due to the reduction of some Mediterranean populations caused by the effects of global change over the last three decades (thermal anomalies, summer development of invasive algae and mucilage, and exceptional storms), as well as a wide range of direct and indirect fishing impacts (Angiolillo et al., 2015; Betti et al., 2020; Bo et al., 2014; Garrabou et al., 2022). Consequently, it is of paramount importance to preserve and protect these highly ecologically important areas (Navarro-Barranco et al., 2023).

Fishing impacts include habitat destruction, direct extraction and mortality of non-target species due to accidental non-target catches (Enrichetti et al., 2019), and chronic contact with fishing gears due to recreational and professional demersal fishing activities (Bavestrello et al., 1997; Betti et al., 2020; Cebrian et al., 2012; Otero et al., 2017). If

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the effects of these activities are prolonged over time, they can lead to evolutionary shifts in population demographics and changes in the function and structure of megabenthic assemblages (Pikitch et al., 2004). Even though artisanal fisheries are often considered to have lesser impact on marine habitats than other fishing activities such as trawling, they still pose a threat to marine ecosystems, especially in areas where they have been practised for long periods of time (Lokrantz et al., 2010). Historically, small-scale fisheries usually work on shallow marine bottoms that consist of a mosaic of rocky substrate combined with some deeper soft sediment assemblages (Demestre et al., 2000). The bathymetric distribution and rugged morphology of artisanal fishing grounds generally restricts the presence of bottom trawling, allowing the development of relatively complex animal forests mostly formed by gorgonians (Díaz et al., 2015). Two of the most common habitat-forming gorgonians in the Mediterranean, *Eunicella cavolini* (up to 60 cm high) (Montseny et al., 2021; Sini et al., 2015) and *Paramuricea clavata* (up to 100 cm high) (Linares et al., 2008), are often caught in fishing nets due to their fan-shaped morphology and size (Dias et al., 2020). As gorgonians are usually long-lived and slow-growing organisms, this fishing activity can have far-reaching and long-lasting effects on their populations (Bennecke and Metaxas, 2017). Furthermore, lost ropes, longlines and demersal nets may either detach the colonies or become entangled, favouring the development of epibionts and leading to increased mechanical stress (Bavestrello et al., 1997; Bo et al., 2014). All these reasons, together with the fact that they are sessile and cannot migrate, make gorgonians suitable as bioindicators of anthropogenic impacts (Kupfner Johnson and Hallock, 2020; Murillo et al., 2020).

Marine Protected Areas (MPAs) in the Mediterranean Sea pretend to preserve the environment, traditional activities, and to help recover-stocks. In North-Eastern Catalonia we encounter the Cap de Creus area (NW Mediterranean Sea) which is under several figures of protection, with two contiguous Sites of Community Importance (SCIs), the 'Park del Cap de Creus', which covers the land and coastal area of the cape and the 'Sistema de cañones submarinos occidentales del Golfo de León', which extends from waters below 60 m and beyond (Sardá et al., 2017). The Cap de Creus SCI was also the first terrestrial-maritime reserve established in Spain (Official State Gazette [BOE], 1998), thus, having had its coastal waters under protection for almost three decades. Yet, artisanal fisheries have remained active in the area uninterruptedly, being of great importance and cultural significance to the local communities. This activity does not only provide food resources, but has also been a source of employment and economic growth for the people living in the coastal villages (Lloret et al., 2010). This type of fishing is normally carried out in small boats (less than 8 m length) and, due to the complexity of the area, fishermen may employ various types of fishing gears, yet trammel nets, gillnets, and pots are the most extensively used targeting species like spiny lobster (*Palinurus elephas)* or the common octopus *(Octopus vulgaris)* (Lloret et al., 2010).

A study conducted on Cap the Creus, identified the fringe coast and canyon margins to be the most potentially impacted by fishing pressure within the area. Apart from that, not much is known about the conservation state of the benthic assemblages occurring in the artisanal fishing grounds of the Cap de Creus (Purroy et al., 2014). However, recent technological advances and increased availability of remotely operated vehicles (ROVs) and video-equipped towed gears have made possible to carry out accurate and quantitative in-situ investigations, allowing controlled samplings and quantitative studies of bottom communities beyond the depth range of traditional scuba diving (~40 m depth) (Gori et al., 2011; Orejas et al., 2009).

Within this context, the MITICAP project (*Implementación de medidas innovadoras de cooperación entre pescadores y científicos para una mejor gestión de la pesca artesanal con el objetivo de mitigar sus impactos en hábitats marinos sensibles*) has emerged with the goal of implementing measures to mitigate the fishing impacts caused by artisanal fishing in Cap de Creus Marine Protected Area (Santín et al., 2022a). As part of the objectives of the MITICAP project, the artisanal fishers guilds (known as *Confraries*; the name given to professional fishers' organizations) of Port de la Selva and Cadaqués (Alt Empordà, Catalonia) have cooperated with researchers by letting them collect data on the by-catch benthic species during their practices, while parallelly participating on a joint ROV exploration of the main fishing grounds of both guilds in order to evaluate their conservation status. The purpose of this study is, thus, i) to analyse the diversity and abundance of benthic species in the artisanal fishing grounds of Cap de Creus and characterise their assemblages, ii) to assess and compare the impacts of artisanal fishing on the different fishing grounds, and iii) to infer into the potential impacts on gorgonian populations (based on size structure, epibiosis and necrosis) as bioindicators of anthropogenic and fishing impacts.

2. Material and methods

2.1. Study area

The Cap de Creus area (42°19′12″ N, 03°19′34″ E) is located in the Gulf of Lions, in the North-Western Mediterranean Sea, being the first maritime-terrestrial Natural Park established in Catalonia. The park covers a total area of 13,886 ha, of which only 3073 ha belong to the marine realm (Law April 1998 (BOE, 1998)). In 2014, Cap de Creus area was also declared a Special Protection Area (SPA) (Area ES5120007) of the Natura 2000 Network (Acord GOV/150/2014 (DOGC, 2014)).

The Cap de Creus littoral and shallow continental shelf includes a wide variety of substrates, being sandy and muddy sediments the most frequent ones and also an abrupt morphology, with rocky outcrops, relict bioherms, erosive features, and planar bedforms (Lo Iacono et al., 2012).

Regarding its hydrological setting, the Liguro-Provenzal-Catalan current (aka Northern Current) from the Gulf of Lions and the input from the Rhône River, together with strong dominant north winds causing water mixing, make this area a highly productive zone (Courp and Monaco, 1990; Lloret et al., 2008). Consequently, it is an area conducive to the agglomeration of pelagic fish and other species of commercial interest (Purroy et al., 2014).

Specifically, after the exchange of information with local fishers, our study focused on the main artisanal fishing grounds identified on this area, those being in Farallons and Illa Portaló (zone A and B, respectively) and Maça d'Oros (zone C), with no more than 100 m depth (Fig. 1).

2.2. Sampling procedure

A total of 18 video transects were recorded onboard the "Atlantic Explorer" vessel between the 24th and July 30, 2018 using a Perseo ROV (Fig. 1).

The ROV was equipped with a high-definition (HD) camera, an additional 4 K camera, depth sensors and two parallel laser beams that provided a fixed scale of 30 cm distance used in the subsequent video analyses. Transect length varied between 150 and 1150 m, with a total distance of 8,5 km recorded. The bathymetric range covered was 10–76 m depth.

Initially, seven transects were targeted for each fishing ground (Fig. 1 A, B, C), but due to bad weather conditions, only four transects could be performed in area C (Maça d'Oros). The rocky areas were prioritised over the sandy areas due to the concentration of artisanal fishing practices in the former. The position of the sampling units was estimated from the recorded geographical coordinates of the initial and final point of each transect. Each transect was recorded starting from the deepest point and proceeding towards the coastline with a constant speed of approximately 0.4 knots. Maximum depth assessed in this study was selected to cover almost the entire sublittoral zone in the study area, from the littoral to the start of the continental shelf. This methodology has been also used in other studies in the same area, such as Ambroso et al. (2013); Coppari et al. (2016); Gori et al. (2011).

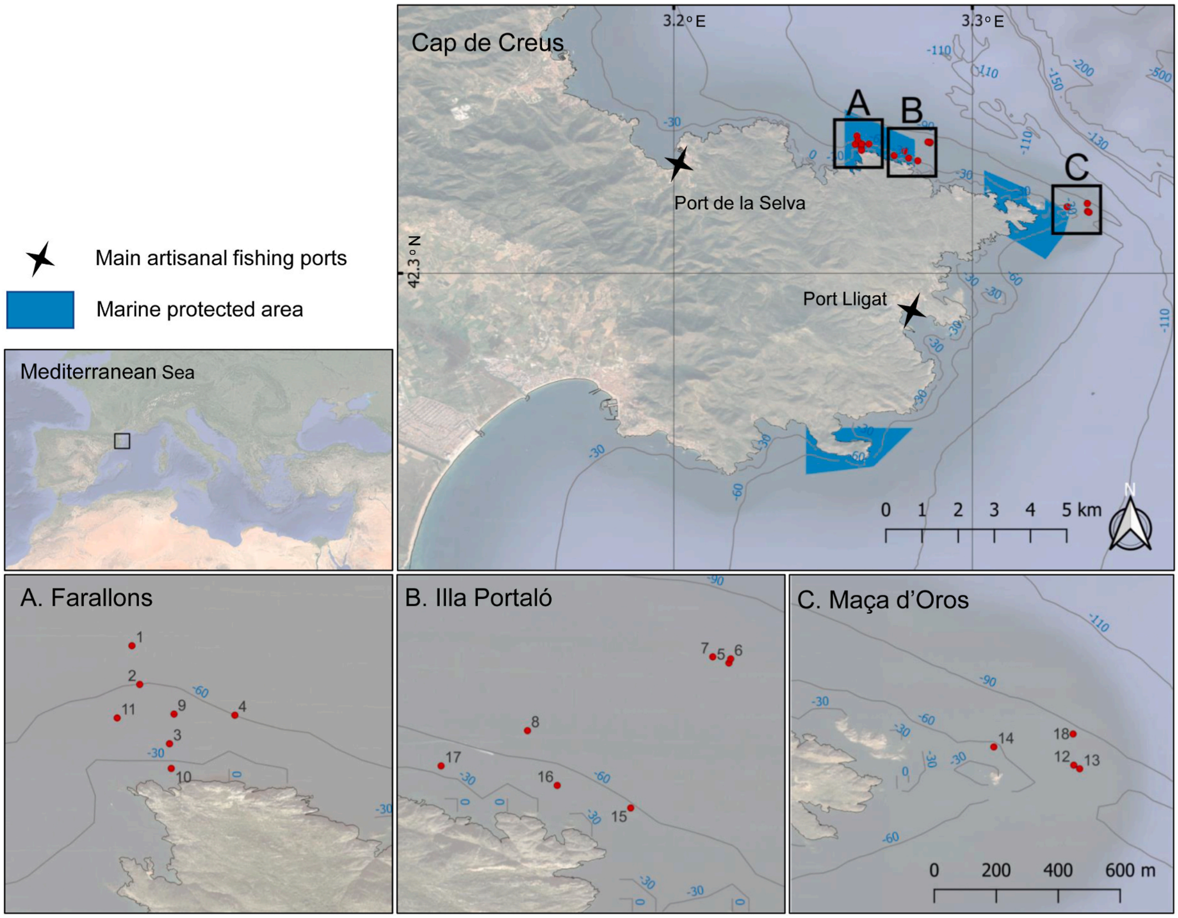

Fig. 1. Map of the study area. Red dots corresponding to sampling transects. A) Farallons B) Illa Portaló and C) Maça d'Oros fishing grounds. Projected view: UTM Zone 31 N (WGS84), with coordinates in decimal degrees.

2.3. Video analysis

Quantitative video analysis was performed following the methodology described by Gori et al. (2011), using Final Cut Pro 7 software (Apple Inc.) and VLC media player. Pauses and loops were removed from the footage to avoid overestimations. Video sequences with poor image quality (e.g. recorded too far away from the sea floor) were discarded from the analysis. A total of 12 h and 10 min was considered suitable for the analysis.

All megabenthic species observed between de 0.3 m laser beams along the video transect were identified to the lowest taxonomic level possible. All species were assigned a time reference based on the beginning of the video transect which was recorded, and posteriorly converted into a position along the transect using the constant speed of the ROV.

Moreover, along each transect additional information was recorded, such as: the type of seabed substrate (soft bottoms, rock and coralligenous), seabed slope (horizontal, sloping or vertical) and depth, recorded every 2 m change.

2.4. Data treatment

2.4.1. Species occupancy, distribution and megabenthic assemblage composition

To analyse the species distribution and composition within the study area, each transect track was divided into a string of 2 m^2 (0.3 m width and 6.66 m long) sampling units, to allow comparison with previous studies on Mediterranean species (Ambroso et al., 2013; Gori et al., 2011; Grinyó et al., 2016).

Each sampling unit was characterised by the fishing ground, the number of the present megabenthic species, as well as by its depth and coverage percentage for each substrate and slope type. Species occurring less than 3 times were excluded, as they could compromise statistical analyses. Megabenthic assemblages were analysed using a non-metric multidimensional scaling ordination (nMDS), with species abundances square root transformed, and ordination performed over a Bray–Curtis dissimilarity matrix.

Furthermore, PERMANOVA (*Adonis* function) and subsequent pairwise tests were performed to test for significant differences amongst assemblages. The nMDS and Adonis test were performed using the R-language function "*metaMDS*" and "*Adonis*", available in the vegan library of the R software platform (Oksanen et al., 2015). Once assemblages were identified, the Indicator value Index (*IndVal*) (Dufrêne and Legendre, 1997) was used to determine which species were representative from each assemblage. The IndVal method allows to identify combinations of species that permit discriminating a group of samples from other samples in the analysis. *IndVal* measures were computed using the function "*indval*" included in the *labdsv* package of the R software (Roberts, 2019).

2.4.2. Impact assessment

Given the difficulty in evaluating the effects of fishing on soft-bottom organisms like pennatulaceans and cerianthids, which tend to retract when disturbed, this study was focused on the main gorgonian species conforming hard habitat assemblages.

The population size structure analysis was conducted on the most abundant gorgonians, namely *Eunicella singularis*, *Paramuricea clavata*, and *Eunicella cavolini*. During the video analysis, when a colony was seen in-between the laser beams and perpendicular to them, an image was taken. Colonies size was measured using the software ImageJ, and further data on gorgonian colony status based on partially epibiosis, partially necrosed, or completely dead gorgonians were recorded. This information together with all the fishing gear and other marine litter identified during the video transects were noted into different categories, to quantify the anthropogenic impacts in each transect.

Size structure of gorgonian populations was analysed in terms of descriptive statistics using distribution parameters such as Skewness and Kurtosis. Skewness is a measure of the symmetry of a distribution using its mean, here reflecting the proportion of small versus large colonies in a gorgonian population. If Skewness is significant ($p < 0.05$) population size structure is asymmetrical. Positive Skewness denotes the prevalence of small size colonies, while negative Skewness denotes the dominance of large size colonies in the population. Kurtosis is a measure of the peakiness of a distribution near its central mode. A significant Kurtosis value ($p < 0.05$) indicates longer tails than would be expected for anormal distribution, and therefore the prevalence of a particular size class in the population (Grinyó et al., 2016; Linares et al., 2008; Santín et al., 2019). Skewness and Kurtosis were calculated by means of the R-language functions *agostino.test* (Komsta and Novomestky, 2012) and *anscombe.test* (Anscombe and Glynn, 1983), which are available in the "moments" library of the R software platform. Additionally, size differences among the three different fishing grounds were tested with Kruskal-Wallis and Dunn's Test. Finally, a correlation (R of Pearson) was made between the density of anthropogenic litter found and the rates of epibiosis, necrosis and dead colonies.

3. Results

3.1. Species occupancy and distribution

Three different megabenthic assemblages could be identified in the nMDS according to the 955 sampling units with 48 different main species, mainly segregated by depth and substrate (Fig. 2). The fishing ground does not appear to affect the segregation of assemblages (Fig. S1).

The first assemblage is represented by horizontal soft bottoms substrates between 50 and 80 m depth. The second is represented by slopping rocky substrates, mostly between 30 and 80 m depth, while the last one corresponded to coralligenous bottoms between 10 and 50 m depth (Fig. 2). The Adonis and subsequent pairwise tests revealed that species assemblages were significantly different for each of the environmental categorizations, with a *p-value* <0.001. The only exception was between slope and vertical sampling units (*p-value* < 0.1).

IndVal analysis showed that soft bottoms were characterised by three main species: the soft coral *Alcyonium palmatum*, the pennatuleacean *Veretillum cynomorium* and the large hydrozoan *Lytocarpia myriophyllum* ($p < 0.001$). Sampling units hosting these species presented higher species richness (1–10 species) and significantly higher densities (6.7 ± 0.4 Average ± SE; PERMANOVA; p-value = 0.003, PSEUDO-F = 9.716) than units without them (species richness: 1–3; 3.4 ± 0.33 Average ± SE).

On hard bottoms the most characteristic species were gorgonians. For coralligenous assemblages, we found *P. clavata* and *E. singularis*, followed by unidentified orange incrusting Porifera and sponges from the genus *Axinella*. On coralligenous concretions between 10 and 50 m depth we encountered an assemblage constituted by the gorgonians *Paramuricea calvata* and *Eunicella singularis*, the soft coral *Alyonium acaule*, different porifera species, of which two demosponge species of the genus *Axinella* stand out, among others (Table 1). The red coral (*Corallium rubrum)* could also be found, although in lower densities (Table S1).

On the contrary, rocky bottoms were characterised by *Eunicella cavolini* followed by *Astrospartus mediterraneus* and *Alcyonium coralloides* ($p < 0.001$) (Table 1). The gorgonian *E. cavolini* clearly dominated this assemblage representing 43% of all observed organisms and reaching densities of 51 col m^{-2}.

The complete results of species contributing to each assemblage is shown in Table S1.

3.2. Impact assessment

3.2.1. Gorgonian size structure

The height of 2202 colonies were measured along the 18 transects. Most populations of *E. cavolini* and *E. singularis* were positively skewed, indicating the dominance of small colonies (mostly between 0 and 30 cm). A third part of *E. cavolini* and nearly half of *E. singularis* colonies showed significant kurtosis indicating that they were slightly more peaked or over centralized than normal distributions. The gorgonian *P. clavata* showed no significant values in Skewness neither in Kurtosis test, which indicates the dominance of medium-sized colonies and no apparent prevalence of a particular size class (Table S. 2 and Figs. S2–S4. Significance of kurtosis and skewness for each of these three species do not seem to be different among fishing grounds.

Instead, size differences among fishing grounds were found. *Eunicella singularis* and *E. cavolini* colonies were significantly smaller in Maça d'Oros and *P. clavata* colonies were smaller in Maça d'Oros and Farallons rather than in Illa Portaló (p-value <0.05) (Table 2).

3.2.2. Impacts on benthic assemblages

Within the marine debris recorded, material related to artisanal or recreational fishing was predominant, with 80.7% being lines and the other 7.2% other fishing gears such as trammel nets or pots. Other marine debris (e.g. plastics or glass bottles) comprised the 12% of all litter found. Most items (87.5%) were found in hard habitats (coralligenous or rocky ones). The highest percentage of litter related to fishing was found in Maça d'Oros (95%), followed by Farallons fishing ground (94%). In Illa Portaló it represented the 75% (Fig. 3).

The density of anthropogenic litter seen ranged between 0 and 0.13 items/m^2 (mean = 0.05 ± 0.04 items/m^2). Apart from that, 742 dead gorgonians were observed along the transects (6.26% of the total colonies), ranging between 0.01 and 1.75 dead gorgonians/m^2 (mean = 0.30 ± 0.39 dead gorgonians/m^2). In general, low percentages of necrosis were observed, with a mean of 1.46% necrosed gorgonians and no transect exceeding 5% (Table 3). Epibiosis rates on gorgonian populations ranged between 0 and 25.48% of colonies affected, with a mean of 16.01% (density between 0 and 0.15 n/m^2; mean = 0.08 ± 0.09 n/m^2). In terms of abundance, the most common epibionts were *A. coralloides, Pentapora* sp., several bryozoans and *Filograna implexa*. No significant correlations were found between the density of anthropogenic debris and the other variables studied.

Regarding comparisons among fishing grounds, Maça d'Oros showed a higher density of anthropogenic items (approximately double), together with twice as many dead colonies. The percentage of colonies with epiphytes is also slightly higher in this area (Table 3).

Results of the main epiphyte species found in each area are shown in Table 4. A strong predominance of *Alcyonium coralloides* as epibiont was detected in Maça d'Oros (70.3%) compared to Farallons (16.6%) and Illa Portaló (24%) (Table 4).

4. Discussion

4.1. Species occupancy and distribution

The segregation by depth and substrate of megabenthic assemblages identified in the present study is in agreement with previous studies on Mediterranean shelfs (e.g. Enrichetti et al., 2019; Grinyó et al., 2018).

4.1.1. Soft sediment assemblages

The most representing species of soft sediment assemblages (*A. palmatum, V. cynomorium* and *L. myriophyllum)* (Fig. 4A and B) are

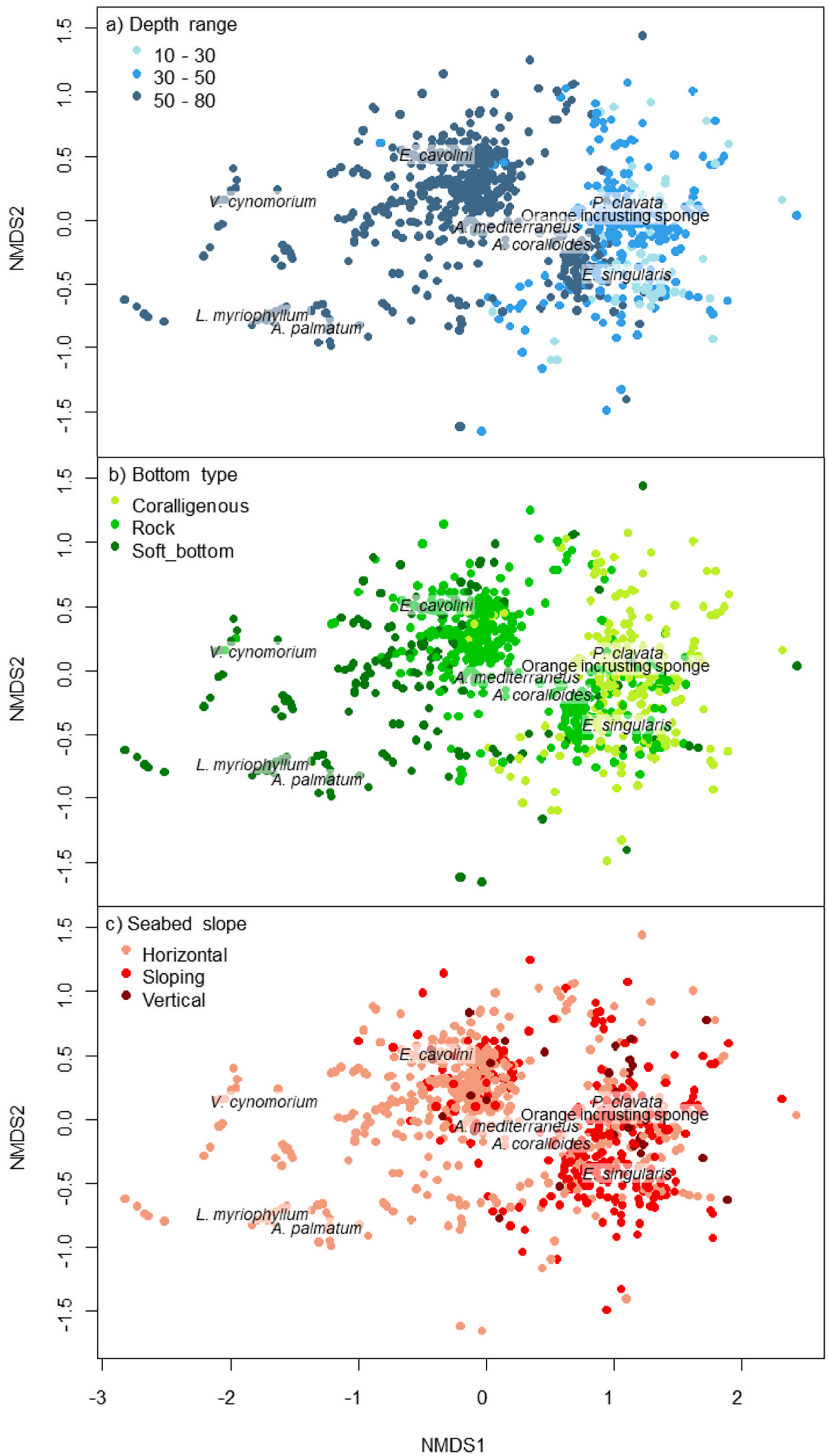

Fig. 2. Non-metric multidimensional scaling (nMDS) ordination plot. Species abundance was square root transformed and analysis performed on Bray–Curtis dissimilarity matrix. Every dot corresponding to a sampling unit (n = 955) containing different species is represented considering (a) depth range, (b) bottom type and (c) seabed slope. A stress estimate of 0.115 was obtained.

Table 1
IndVal analysis, with the average and maximum density of the most contributing species to each community (IndVal >0.1). Density values are only given for those species which were reliably identified. Avg.: average density ± standard deviation; Max: maximum density.

	IndVal	Probability	Avg. (ind./m^2)	Max. (ind./m^2)
Coralligenous				
Paramuricea clavata	0.5280	0.001	2.94 ± 2.7	13
Eunicella singularis	0.4688	0.001	5.81 ± 5.1	23
Orange encrusting Porifera	0.2695	0.001	–	–
Axinella spp.	0.2327	0.001	2.04 ± 3.15	20
Axinella polypoides	0.1715	0.001	1 ± 0.82	5
Red encrusting Porifera	0.1599	0.001	–	–
Alcyonium acaule	0.1411	0.001	2.98 ± 3.15	11
Halocynthia papillosa	0.1408	0.001	0.81 ± 0.42	2
Holothuria spp.	0.1328	0.001	0.84 ± 0.52	2
Myriapoda truncata	0.1328	0.001	0.82 ± 0.47	2
Rock				
Eunicella cavolini	0.5139	0.001	7.30 ± 8.45	51
Astrospartus mediterraneus	0.3947	0.001	1.15 ± 1.25	4
Alcyonium coralloides	0.2363	0.001	0.44 ± 1.46	10
Soft bottom				
Alcyonium palmatum	0.3918	0.001	1.15 ± 0.93	6
Veretillum cynomorium	0.2890	0.001	0.78 ± 0.50	3
Lytocarpia myriophyllum	0.1385	0.001	1.78 ± 2.31	15

commonly reported in soft sediment shelve environments of the western and central Mediterranean (De Juan et al., 2013; Dominguez-Carrió et al., 2022; Petović et al., 2021).

These species are particularly important in soft sediment habitats as they provide three-dimensional structure in an otherwise homogeneous environment increasing local diversity and biomass (Bastari et al., 2018; Di Camillo et al., 2013), as suggested by the higher species richness and densities of associated species found in sampling units hosting these species.

Additionally, these species' densities (Table 1) were higher than in previous studies conducted in outer shelf environments (>80 m depth) (Di Camillo et al., 2013; Dominguez-Carrió et al., 2022; Grinyó et al., 2020). These organisms are extremely susceptible to bottom trawling and in other areas of the Mediterranean exposed to trawling they have become scarce (De Juan et al., 2007; Di Camillo et al., 2013). It is likely that these higher abundances indicate that these communities are well preserved and artisanal fishing does not pose a substantial toll as it mostly targets rock dwelling species (e.g. common octopus, spiny lobster, rockfish).

4.1.2. Inner-shelf rock assemblages

The dominance of *E. cavolini* (Fig. 4C) in rocky outcrops between 30 and 80 m depth is in accordance with previous observations (Grinyó et al., 2016). Indeed, this species has shown to play a paramount role in coral gardens in mesophotic and circalittoral environments in outer shelf, shelf edge and seamount environments in other areas of the western Mediterranean (Bo et al., 2011; Cau et al., 2017; Dominguez-Carrió et al., 2022; Grinyó et al., 2016; Lo Iacono et al., 2020). *Paramuricea clavata* (and *P. macrospina)* were also present in this assemblage, though they occurred at lower densities than in other areas of the Western Mediterranean (Bo et al., 2011; Grinyó et al., 2016). In fact, *P. clavata*, has been described to occur at lower densities in shelf environments (Grinyó et al., 2016). Contrary, prior observations of *P. macrospina* on the Balearic Islands or in the Tyrrhenian Sea, revealed large densities of this species monopolising wide extensions, in contrast with the modest *P. macrospina* densities found in this study. Furthermore, the importance of *A. mediterraneus*in this assemblage (Table 1, Fig. 4D) agrees with Biel-Cabanelas et al., 2023, who already reported that this ophiuroid occurs at unusual high densities in inner-shelf rocky environments in the study area.

4.1.3. Coralligenous assemblage

All of the species found in coralligenous concretions are common components of coralligenous assemblages in Western Mediterranean environments (Ballesteros, 2006). The most abundant species found in this assemblage, i. e. *E. singularis* and *P. clavata* (Fig. 4eE and F) representing respectively 39% and 16% of all observed organism, in agreement with previous observations on the Western Mediterranean (Gori

Table 2
Demographic parameters (minimum, average and maximum height) of the main gorgonian species occurring on the evaluated fishing grounds. All values are given in cm; average values include standard deviation. Mean values per fishing ground were calculated using only the transects where the species were recorded. Populations with an asterisk '*' indicates a gorgonian abundance below 30 individuals, considered to be the minimal threshold for properly estimating gorgonian demography (Linares et al., 2008; Gori et al., 2011).

Fishing Ground			*E. singularis*			*E. cavolini*			*P. clavata*		
	Transect	Depth (m)	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
A. Farallons	1	66–74	–	–	–	8	18.5 ± 11.4*	44.5	–	–	–
	2	40–60	3.1	24 ± 15.8	71	4.5	31.6 ± 13.1*	52	25.8	44.4 ± 11.8*	57
	3	20–40	7	26.3 ± 15	79.1	–	–	–	22	40.4 ± 13.31*	56.8
	4	25–65	11.3	26.8 ± 10.6	47.3	5.1	21.7 ± 8.05	40.9	15.1	24.9 ± 12.32*	40.7
	9	40–60	–	–	–	5.6	27.4 ± 12.2	58.7	–	–	–
	10	10–50	8.7	27 ± 11.6	62.6	–	–	–	14.1	45.5 ± 22.8*	81.6
	11	50–60	–	–	–	4.2	26.8 ± 17.17	87.9	–	–	–
	Mean	**10–74**	**3.1**	**25.9 ± 13.6**	**79.1**	**4.2**	**26 ± 13.1**	**87.9**	**14.1**	**41.2 ± 13.9**	**81.6**
B. Illa Portaló	5	70–80	–	–	–	14	28.3 ± 11	75.5	–	–	–
	6	65–80	–	–	–	4.8	26.1 ± 10.2	55.4	–	–	–
	7	65–75	–	–	–	5	25 ± 10.8	76.7	–	–	–
	8	65–75	4.6	24.7 ± 12.1	64.4	6.2	23.9 ± 9.7	53.7	6.2	67.9 ± 29.1*	113
	15	45–60	–	–	–	–	–	–	–	–	–
	16	35–45	4.1	23.9 ± 14.2	91	6.2	23.9 ± 9.7	53.7	10	49.2 ± 25.4	117.9
	17	15–45	4.6	27 ± 14	72.8	4.6	26.2 ± 13.9	72.8	15.5	66.7 ± 37.6*	124.3
	Mean	**15–80**	**4.1**	**24.5 ± 13.6**	**91**	**4.6**	**25.8 ± 10.4**	**76.7**	**6.2**	**57.2 ± 29**	**124.3**
C. Maça d'Oros	12	55–70	–	–	–	4.8	22 ± 10.2	58.7	–	–	–
	13	55–60	5.5	19.6 ± 9.5	59.6	–	–	–	–	–	–
	14	35–55	–	–	–	7	24.1 ± 10.1	66.8	17.5	34.6 ± 12.4*	56
	18	60–75	5.2	24.1 ± 12.2	59.4	–	–	–	–	–	–
	Mean	**35–75**	**5.2**	**21.9 ± 11.2**	**59.6**		**22.6 ± 10.2**			**34.6 ± 12.4***	

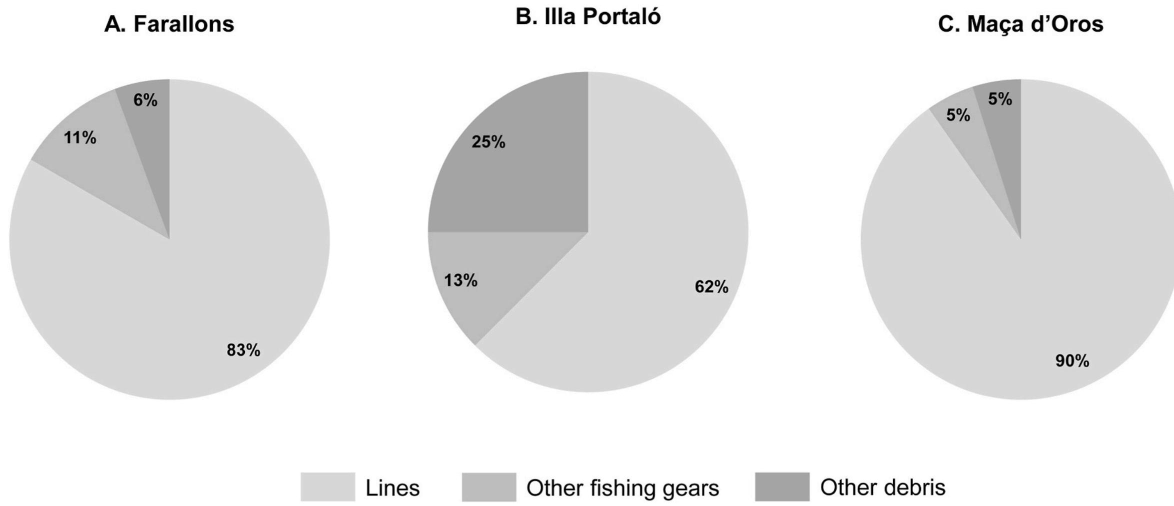

Fig. 3. Percentage composition of marine litter found on the sea bottom in each fishing ground.

Table 3
Summary table including the density of anthropogenic items (fishing gears, human debris, etc.) and proxies for gorgonian population health (percentage of dead, necrosed and colonies with epiphytes within a population) observed during the ROV video analysis for each transect and each fishing ground. Numbers in brackets indicate the abundance of anthropogenic items, dead necrosed and colonies with epiphytes per transect.

	Transect	Depth (m)	Anthropogenic items (N°/m^2)	Dead colonies (%)	Necrosed colonies (%)	Colonies with epiphytes (%)
A. Farallons	1	66–74	0.013 (1)	1.7 (1)	0 (0)	0 (0)
	2	40–60	0.000 (0)	1.3 (6)	0.7 (3)	6.9 (31)
	3	20–40	0.042 (4)	0.4 (2)	1.3 (6)	11.2 (50)
	4	25–65	0.026 (9)	1.6 (6)	1.3 (5)	18.6 (70)
	9	40–60	0.045 (8)	4.6 (58)	1.3 (16)	16.7 (201)
	10	10–50	0.089 (4)	7.1 (19)	1.6 (4)	18.6 (46)
	11	50–60	0.000 (0)	7.9 (25)	1.4 (4)	25.2 (73)
	Mean	**10–74**	**0.027 (26)**	**3.67 (117)**	**1.2 (38)**	**15.3 (471)**
B. Illa Portaló	5	70–80	0.077 (4)	2.6 (4)	0 (0)	12.6 (19)
	6	65–80	0.134 (7)	3.8 (26)	3.2 (21)	14.3 (95)
	7	65–75	0.018 (2)	4.3 (27)	2.7 (16)	14.7 (88)
	8	65–75	0.004 (1)	15.8 (59)	4.8 (15)	25.5 (80)
	15	45–60	0.014 (3)	3.4 (24)	0.7 (5)	20.8 (144)
	16	35–45	0.117 (11)	3.3 (32)	1.5 (14)	12.2 (114)
	17	15–45	0.000 (0)	1.5 (7)	0.6 (3)	14.6 (68)
	Mean	**15–80**	**0.031 (28)**	**4.47 (179)**	**1.9 (74)**	**15.9 (608)**
C. Maça d'Oros	12	55–70	0.024 (6)	8.2 (96)	0.5 (5)	15.3 (165)
	13	55–60	0.059 (8)	14.1 (237)	0.3 (4)	22.3 (322)
	14	35–55	0.090 (15)	5.3 (67)	0.8 (9)	12.4 (149)
	18	60–75	0.085 (12)	8.4 (46)	3.6 (18)	13.0 (65)
	Mean	**35–75**	**0.059 (41)**	**9.55 (446)**	**0.852 (36)**	**16.6 (701)**

Table 4
Main epiphyte species on gorgonian colonies in each fishing ground. A colony may have more than one species of epibiont. Abbreviated species are *Alcyonium coralloides* (*A. coralloides*) and *Filograna implexa* (*F. implexa*)

	A. coralloides %	Bryozoa %	*F. implexa* %	*Pentapora* sp. %
A. Farallons	16,6	22,5	12,3	25,9
B. Illa Portaló	24,0	15,0	5,1	16,0
C. Maça d'Oros	70,3	10,8	6,6	14,1

et al., 2011; Grinyó et al., 2016). Mostly, *E. singularis* occurred on sloping grounds (55% of colonies) and *P. clavata* on horizontal (51% of colonies) ones. This stands in contrast to earlier research on other coralligenous grounds, which mostly linked *P. clavata* to vertical grounds and *E. singularis* to horizontal ones (Gori et al., 2011; Grinyó et al., 2016). It is likely that this unusual pattern reflects small scale variability in the area. Furthermore, *E. singularis, P. clavata*, *A. palmatum* and *A. polypoides* densities were lower than those previously reported along Cap de Creus (Gori et al., 2011; Ambroso et al., 2013; Coppari et al., 2016). It is unclear if these lower densities respond to local variability, fishing pressure or derive from mass mortality events that have been occurring over the past decade in the study area (Garrabou et al., 2022).

4.2. Impact assessment

4.2.1. Gorgonian size structure

Three key ecosystem engineers – *E. singularis, E. cavolini, and P. clavata* – were described. Despite playing a crucial role in marine benthic ecosystems and offering refuge to a wide variety of other species, member species of the order Malacalcyonacea (McFadden et al., 2022) have also been identified as the species most negatively impacted by artisanal fisheries (Dias et al., 2020).

A previous study on *E. cavolini* at various sites of the Mediterranean Sea pointed to higher densities but also smaller colonies (Sini et al.,

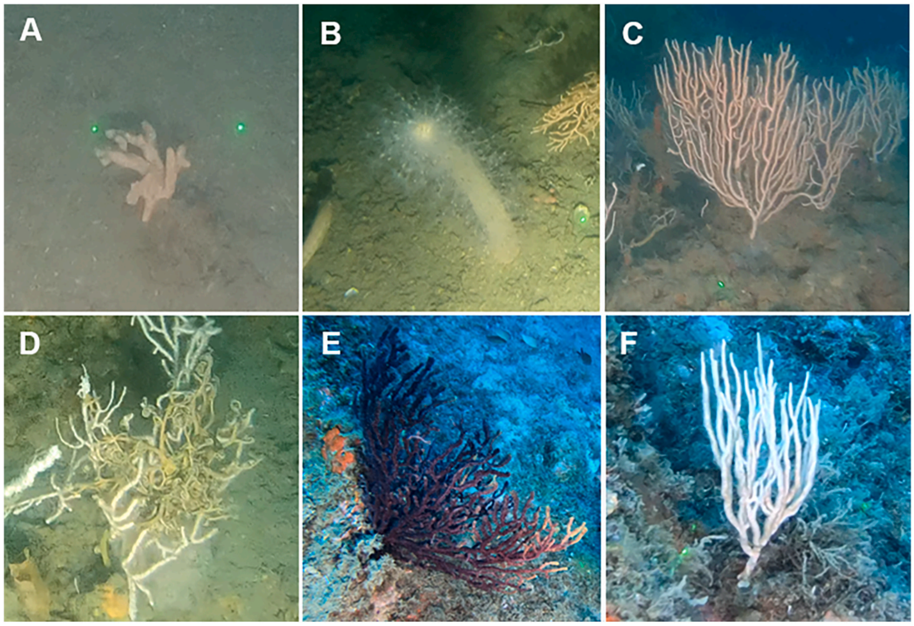

Fig. 4. Most contributing species to the assemblages. (A) *Alcyonium palmatum*, (B) *Veretillum cynomorium*, (C) *Eunicella cavolini*, (D) *Astrospartus mediterraneus*, (E) *Paramuricea clavata*, and (F) *Eunicella singularis*. Images from the ROV video recordings.

2015). This can be due to higher environmental instability (e.g. hydrodynamism, food supply, temperature, light exposure), typical from shallower waters (<40 m). Contrary, our colonies were found beyond 37.5 m. Nonetheless, our data agrees with the conclusion of Sini and collaborators, in which density is overall inversely related to height, supporting the idea that recruitment is driven by intra-specific competition mechanisms, where the lack of large colonies enhances recruitment success (Sini et al., 2015). If we compare our data to the nearby Balearic Islands (Grinyó et al., 2016), it seems that Cap de Creus is able to sustain higher densities and considerably bigger colonies. This could be attributed to the fact that in the Balearic Islands this species mostly occurred alongside other anthozoans (Grinyó et al., 2016, 2018), thus having to compete for substrate, whereas in the study area this species mostly occurred forming monospecific aggregations.

The same happened with *E. singularis* in the study area compared to denser populations but also smaller colonies than in the Menorca Channel (Grinyó et al., 2016). However, most *E. singularis* colonies in the Menorca Channel grew on maërl whereas in the study area they mainly grew on rock. It is likely that substrate stability may reinforce the development of denser *E. singularis* populations. Additionally, unlike the Balearic Archipelago, the study area is under the influence of nutrient-rich waters derived from river runoff in the gulf of Lions, creating suitable conditions for gorgonian-dominated assemblages to fully develop (Gori et al., 2017). In fact, in shallower waters around Cap de Creus (13–27 m), the colonies of *E. singularis* are smaller but grow in denser populations (Linares et al., 2008). Moreover, it has been demonstrated the preference of the larvae of *E. singularis* to seek for a lighter place to settle (Weinberg, 1979b), which could lead to igher recruitment rates and densities in lower depths.

On the contrary, *P. clavata* colonies were found in less dense populations but higher heights compared to other studies in the same area in shallower waters (25–30 m, Maça d'Oros) (Linares et al., 2008). This differences of height and densities in Cap de Creus can be due to the existence of a carrying capacity (maximum population size of a species that can be sustained in a specific environment) (Linares et al., 2008) but also to the ecological preference of low light conditions of *P. clavata* (Ballesteros, 2006).

Population size structures of *E. singularis* and *E. cavolini* were mostly asymmetrical and positively skewed suggesting higher recruitment rates than *P. clavata*, which had no prevalence for any size-class (Linares et al., 2008). Some studies suggest that the prevalence of small colonies could be associated with impacted populations due to fishing activities (Althaus et al., 2009; Grinyó et al., 2016). In the study area, it was observed that size class 2 (10–20 cm) prevailed among *E. singularis* populations, while size class 3 (20–30 cm) was predominant in *E. cavolini* populations. This stands in contrast to *E. singularis* populations found in shallower waters within the same area, where size class 1 (0–10 cm) dominated (Linares et al., 2008).

4.2.2. *Impact on benthic assemblages*

The dominance of fishing lines among the marine debris found in most fishing locations (see Fig. 3) is consistent with those of a prior investigation in adjacent areas (Dominguez-Carrió et al., 2020) and with research developed in the Tyrrhenian Sea (Angiolillo et al., 2015). Nevertheless, other areas with similar artisanal fishing tradition appear to be more impacted, such as the "Maledetti Shoal" in the Ligurian Sea, with a density of marine debris 10 times a higher than the present study (Enrichetti et al., 2019). For instance, the study conducted in the "Maledetti Shoal", revealed that, on average, 40% of the structuring anthozoans showed signs of impact, such as necrotic portions, overgrowth of epibiotic organisms, and direct entanglements of colonies by fishing gears (Enrichetti et al., 2019). Another case study in Portofino MPA (NW Mediterranean Sea) reported that 53% of the colonies of *P. clavata* and 36% of the colonies of *E. cavolini* showed traces of impact (Betti et al., 2020). In contrast, the predominant use of trammel nets with lower lengths and pots by fishers in the study area accounts for benthic ecosystems associated with lower damage (Baena et al., 2022).

In European seas, around 30% of all marine litter that accumulates on shelf, slope and canyon habitats can be attributed to abandoned, lost, or discarded fishing gear (ALDFG; Pham et al., 2014). This percentage can reach 50–90% in traditional fishing grounds as seen in the present study or in other areas, such as Campania, Sicily or Liguria (Angiolillo et al., 2015; Consoli et al., 2018; Enrichetti et al., 2020).

Present results of epibiosis rates on gorgonian populations match with a previous study conducted near the study area, in Medes Islands (South from Cap de Creus) which indicated that between 10% and 33% of the colonies in unprotected populations were partially colonised by epibionts, most likely resulting from tissue injury (Tsounis et al., 2012).

On the contrary, only between 4% and 10% of the populations in a Marine Protected Area were affected (Tsounis et al., 2012), suggesting that fishing activities or other disturbances of anthropogenic origin contribute to the damage and consequent epibiosis of the gorgonian colonies (Bavestrello et al., 1997; Tsounis et al., 2012).

In this regard, the proportion of colonies with *Alcyonium coralloides* as epiphytes in Maça d'Oros was three and four times higher than in the other fishing grounds (Table 4). This octocoral epibiont is likely to grow on the apical axis of injured or dead gorgonian colonies (Quintanilla et al., 2013; Weinberg, 1979a) so in high proportions it could be an indicator of an impacted ecosystem. Maça d'Oros fishing ground is an area of confluence for artisanal vessels from different fishermen's guilds (Gómez and Riera Aragó, 2007) in accordance with the greater presence of ALDG, and therefore it could be subjected to a harder anthropogenic pressure. This could result in more impacted populations, as suggested by the significantly smaller colonies and the higher proportions of dead colonies and colonies with epibionts.

Overall, the results of the present study reaffirm the vulnerability and the high degree of exposure to fishing impacts that gorgonian species specially, but also other structural sessile marine benthic organisms, face. Moreover, species that rely on structural benthic organisms providing them habitat and resources can be indirectly affected by the loss of live corals (Lokrantz et al., 2010; Bonin et al., 2011). In fact, some studies observed a decline of coral specialized fish species, changes in the feeding behaviour or direct impacts by the ingestion or entanglement of ALDG on different species in degradated habitats (Alvarez-Filip et al., 2015; Beneli et al., 2020; Link et al., 2019); highlighting its importance.

The fishing impacts and affections (rates of epibiosis and necrosis) in gorgonians detected in our study are lower compared to previous studies in other Mediterranean areas. Also, the presence of large sizes of gorgonian species is an indicator of good preservation. Different reasons could explain the lower impact in the study area versus other areas previously studied, but mainly, fishers reported among their habits to frequently change the draft area and do not usually fish during the winter, so the impact may also be reduced. To fully comprehend the conservation status of the studied area and its link to anthropogenic disturbances, additional research and a more complete and continuous on-time dataset is needed. Also, due to the higher number of impacts found in other Mediterranean fishing grounds with different fishing habits, we insist as has been done by previous authors (e.g., Tsounis et al., 2012; Giovos et al., 2018; Gómez et al., 2021) on the importance of better reporting the characteristics of recreational activities conducted in the area to better assess the possible impacts of fishing activities and set adequate conservation and mitigation measures in accordance with the other stakeholders of maritime activities (Lloret et al., 2008; Gómez et al., 2021). Collaborative efforts with experienced local fishers and scuba divers, who possess extensive knowledge of the benthic communities, could enhance the recovery of ALDG. Simultaneously, collaboration with fishers would contribute to raising awareness about the potential impacts their activities might have on benthic ecosystems and, consequently, on the catches they are interested in (Dominguez-Carrió et al., 2020; Santín et al., 2022a, 2022b).

Nevertheless, it is important not to drop our guard too far and remember the high vulnerability of those ecosystems and so, continue monitoring fishing activities and progressively introduce measures to mitigate their impacts.

5. Conclusions

An impact assessment of marine benthic ecosystems in artisanal fishing grounds in Cap de Creus area through collaborative work by marine biologists and local artisanal fishers has been reported for the first time. Three megabenthic assemblages have been identified, mainly segregated by depth and substrate. The affections on gorgonian species in terms of epibiosis and necrotic tissue are lowered compared to other areas previously studied in the Mediterranean under fishing and other anthropogenic pressures. Even though the presence of high individuals is an indicator of hope we should remember that marine sessile benthic species are highly vulnerable to all anthropogenic pressures and should not be underestimated. A better understanding of recreational fisheries in coexistence with other activities that could harm and threaten the marine benthic ecosystems are essential, as well as better management measures and new ways to mitigate the existing impacts.

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Sample CRediT author statement

Andrea Higueruelo: Conceptualization, Investigation, data acquisition, data curation, formal analysis, Writing - original draft, Writing - review & editing, Andreu Santín: Investigation, conceptualization, methodology, data acquisition, data curation, supervision, Writing - review & editing, Janire Salazar: Writing - Review & Editing, Stefano Ambroso: Writing - Review & Editing, Anna Soler-Membrives: Investigation, conceptualization, methodology, data acquisition, data curation, supervision, Writing - review & editing, Jordi Gruinyó: Funding acquisition, project administration, conceptualization, methodology, data acquisition, supervision, writing-review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Jordi Grinyo reports financial support was provided by Biodiversity Foundation.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marenvres.2023.106211.

References

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

Ambroso, S., Gori, A., Dominguez-Carrió, C., Gili, J.M., Berganzo, E., Teixidó, N., Greenacre, M., Rossi, S., 2013. Spatial distribution patterns of the soft corals *Alcyonium acaule* and Alcyonium palmatum in coastal bottoms (Cap de Creus, northwestern Mediterranean Sea). Mar. Biol. 160 (12), 3059–3070. https://doi.org/10.1007/s00227-013-2295-4.

Angiolillo, M., Lorenzo, B. di, Farcomeni, A., Bo, M., Bavestrello, G., Santangelo, G., Cau, A., Mastascusa, V., Cau, A., Sacco, F., Canese, S., 2015. Distribution and assessment of marine debris in the deep Tyrrhenian Sea (NW Mediterranean Sea, Italy). Mar. Pollut. Bull. 92 (1–2), 149–159. https://doi.org/10.1016/j.marpolbul.2014.12.044.

Anscombe, F.J., Glynn, W.J., 1983. Distribution of the kurtosis statistic b2 for normal samples. Biometrika 70 (1), 227–234. https://doi.org/10.1093/biomet/70.1.227.

Alvarez-Filip, L., Paddack, M.J., Collen, B., Robertson, D.R., Côté, I.M., 2015. Simplification of Caribbean reef-fish assemblages over decades of coral reef degradation. PLoS One 10, 1–14. https://doi.org/10.1371/journal.pone.0126004.

Baena, P., Quintanilla, E., Ambroso, S.G.J., Santín, A., Salazar, J., Gili, J., Gori, A., 2022. Effective management measures to reduce the bycatch of cold-water gorgonians and support sustainable artisanal fishing on the mediterranean continental shelf. In: 3 Rd Mediterranean Symposium on the Conservation of the Dark Habitats, p. 59.

Ballesteros, E., 2006. Mediterranean coralligenous assemblages: a synthesis of present knowledge. Oceanogr. Mar. Biol. 44, 123–195.

Bastari, A., Pica, D., Ferretti, F., Micheli, F., Cerrano, C., 2018. Sea pens in the Mediterranean Sea: habitat suitability and opportunities for ecosystem recovery. ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 75 (5), 1722–1732. https://doi.org/10.1093/icesjms/fsy010.

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

Beneli, T.M., Pereira, P.H.C., Nunes, J.A.C.C., Barros, F., 2020. Ghost fishing impacts on hydrocorals and associated reef fish assemblages. Mar. Environ. Res. 161, 105129 https://doi.org/10.1016/J.MARENVRES.2020.105129.

Bennecke, S., Metaxas, A., 2017. Effectiveness of a deep-water coral conservation area: evaluation of its boundaries and changes in octocoral communities over 13 years. Deep Sea Res. Part II Top. Stud. Oceanogr. 137, 420–435. https://doi.org/10.1016/j.dsr2.2016.06.005.

Betti, F., Bavestrello, G., Bo, M., Ravanetti, G., Enrichetti, F., Coppari, M., Cappanera, V., Venturini, S., Cattaneo-Vietti, R., 2020. Evidences of fishing impact on the coastal gorgonian forests inside the Portofino MPA (NW Mediterranean Sea). Ocean Coast Manag. 187 (January) https://doi.org/10.1016/j.ocecoaman.2020.105105.

Biel-Cabanelas, M., Santín, A., Montasell, M., Salazar, J., Baena, P., Viladrich, N., Montseny, M., Corbera, G., Ambroso, S., Grinyó, J., 2023. From emblematic to problematic: the case of Astrospartus mediterraneus (Risso, 1826) (Echinodermata: ophiuroidea) in the artisanal fishing grounds of the Cap de Creus area (NW Mediterranean Sea). Continent. Shelf Res. 255 https://doi.org/10.1016/j.csr.2023.104925.

Bo, M., Bertolino, M., Borghini, M., Castellano, M., Covazzi Harriague, A., et al., 2011. Characteristics of the mesophotic megabenthic assemblages of the vercelli seamount (north Tyrrhenian Sea). PLoS One 6 (2), e16357. https://doi.org/10.1371/journal.pone.0016357.

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

BOE., 1998. Ley 4/1998, de 12 de marzo, de Protección de Cap de Creus, 127. Comunidad Autónoma de Cataluña, pp. 17613–17626.

Bonin, M.C., Almany, G.R., Jones, G.P., 2011. Contrasting effects of habitat loss and fragmentation on coral-associated reef fishes. Ecology 92, 1503–1512. https://doi.org/10.1890/10-0627.1.

Cau, A., Alvito, A., Moccia, D., Canese, S., Pusceddu, A., Rita, C., Angiolillo, M., Follesa, M.C., 2017. Submarine canyons along the upper Sardinian slope (Central Western Mediterranean) as repositories for derelict fishing gears. Mar. Pollut. Bull. 123 (1–2), 357–364. https://doi.org/10.1016/j.marpolbul.2017.09.010.

Cebrian, E., Linares, C., Marschal, C., Garrabou, J., 2012. Exploring the effects of invasive algae on the persistence of gorgonian populations. Biol. Invasions 14 (12), 2647–2656. https://doi.org/10.1007/s10530-012-0261-6.

Consoli, P., Falautano, M., Sinopoli, M., Perzia, P., Canese, S., Esposito, V., Battaglia, P., Romeo, T., Andaloro, F., Galgani, F., Castriota, L., 2018. Composition and abundance of benthic marine litter in a coastal area of the central Mediterranean Sea. Mar. Pollut. Bull. 136, 243–247. https://doi.org/10.1016/j.marpolbul.2018.09.033.

Coppari, M., Gori, A., Viladrich, N., Saponari, L., Canepa, A., Grinyó, J., Olariaga, A., Rossi, S., 2016. The role of Mediterranean sponges in benthic-pelagic coupling processes: aplysina aerophoba and Axinella polypoides case studies. J. Exp. Mar. Biol. Ecol. 477, 57–68. https://doi.org/10.1016/j.jembe.2016.01.004.

Courp, T., Monaco, A., 1990. Sediment dispersal and accumulation on the continental margin of the Gulf of Lions: sedimentary budget. Continent. Shelf Res. 10 (9–11), 1063–1087. https://doi.org/10.1016/0278-4343(90)90075-W.

Crespo, D., Pardal, M.Â., Ecological and economic importance of benthic communities, 2020. Life below Water, pp. 1–11, 10.1007978-3-319-71064-8_5-1.

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

De Juan, S., Lo Iacono, C., Demestre, M., 2013. Benthic habitat characterisation of soft-bottom continental shelves: integration of acoustic surveys, benthic samples and trawling disturbance intensity. Estuar. Coast Shelf Sci. 117, 199–209. https://doi.org/10.1016/j.ecss.2012.11.012.

Demestre, M., Sánchez, P., Abelló, P., 2000. Demersal fish assemblages and habitat characteristics on the continental shelf and upper slope of the north-western Mediterranean. J. Mar. Biol. Assoc. U. K. 80 (6), 981–988. https://doi.org/10.1017/s0025315400003040.

Di Camillo, C.G., Boero, F., Gravili, C., Previati, M., Torsani, F., Cerrano, C., 2013. Distribution, ecology and morphology of Lytocarpia myriophyllum (Cnidaria: Hydrozoa), a Mediterranean Sea habitat former to protect. Biodivers. Conserv. 22 (3), 773–787. https://doi.org/10.1007/S10531-013-0449-9.

Dias, V., Oliveira, F., Boavida, J., Serrão, E.A., Gonçalves, J.M.S., Coelho, M.A.G., 2020. High coral bycatch in bottom-set gillnet coastal fisheries reveals rich coral habitats in southern Portugal. Front. Mar. Sci. 7, 993. https://doi.org/10.3389/fmars.2020.603438.

Díaz, D., Bo, M., Gaamour, A., Ambroso, S., Bavestrello, G., Bed Abdallah, L., Ben Salem, S., Benmassaoued, R., Canese, S., Cerasi, S., Cherif, M., Djabou, H., Dominguez-Carrió, C., Goñi, R., Grinyó, J., Gutiérrez, V., Jaziri, S., Khemiri, S., Koched, W., Nurus, P., Mallol, S., Misaoui, H., Ben Amor, M.M., Muñoz, A., Palomeque, R., Profeta, A., Rjeibi, O., Santín, A., Gili, J.M., 2015. Towards Ecosystem Conservation and sustainable artisanal fisheries in the Mediterranean basin. In: ICES Annual Science Conference 2015. ICES CM 2015/F:23, Copenhagen, Denmark.

Dominguez-Carrió, C., Sanchez-Vidal, A., Estournel, C., Corbera, G., Riera, J.L., Orejas, C., Canals, M., Gili, J.M., 2020. Seafloor litter sorting in different domains of Cap de Creus continental shelf and submarine canyon (NW Mediterranean Sea). Mar. Pollut. Bull. 161, 111744 https://doi.org/10.1016/j.marpolbul.2020.111744.

DOGC, 2014. ACORD GOV/150/2014, de 4 de novembre, pel qual es declaren zones especials de conservació de la regió biogeogràfica mediterrània, integrants de la xarxa Natura 2000, se n'aprova l'instrument de gestió, i s'autoritza el conseller de Territori i Sostenibilitat per poder actualitzar els annexos 2, 3 i 4 de l'Acord GOV/176/2013, pel qual es declaren les zones especials de conservació de la regió biogeogràfica alpina, integrants de la xarxa Natura 2000, i se n'aprova l'instrument de gestió. Diari oficial de la Generalitat de Catalunya 6744. https://dogc.gencat.cat/ca/document-del-dogc/?documentId=674149.

Dominguez-Carrió, C., Riera, J.L., Robert, K., Zabala, M., Requena, S., Gori, A., Orejas, C., Lo Iacono, C., Estournel, C., Corbera, G., Ambroso, S., Uriz, M.J., López-González, P.J., Sardá, R., Gili, J.M., 2022. Diversity, structure and spatial distribution of megabenthic communities in Cap de Creus continental shelf and submarine canyon (NW Mediterranean). Prog. Oceanogr. 208, 102877 https://doi.org/10.1016/j.pocean.2022.102877.

Dufrêne, M., Legendre, P., 1997. Species assemblages and indicator species : the need for a flexible asymmetrical approach. Ecol. Monogr. 67 (3), 345–366.

Enrichetti, F., Bava, S., Bavestrello, G., Betti, F., Lanteri, L., Bo, M., 2019. Artisanal fishing impact on deep coralligenous animal forests: a Mediterranean case study of marine vulnerability. Ocean Coast Manag. 177 (November 2018), 112–126. https://doi.org/10.1016/j.ocecoaman.2019.04.021.

Enrichetti, Francesco, Dominguez-Carrió, C., Toma, M., Bavestrello, G., Canese, S., Bo, M., 2020. Assessment and distribution of seafloor litter on the deep Ligurian continental shelf and shelf break (NW Mediterranean Sea). Mar. Pollut. Bull. 151 https://doi.org/10.1016/j.marpolbul.2019.110872.

Garrabou, J., Gómez-Gras, D., Medrano, A., Cerrano, C., Ponti, M., Schlegel, R., Bensoussan, N., Turicchia, E., Sini, M., Gerovasileiou, V., Teixido, N., Mirasole, A., Tamburello, L., Cebrian, E., Rilov, G., Ledoux, J.B., Souissi, J. Ben, Khamassi, F., Ghanem, R., et al., 2022. Marine heatwaves drive recurrent mass mortalities in the Mediterranean Sea. Global Change Biol. 28 (19), 5708–5725. https://doi.org/10.1111/gcb.16301.

Giovos, I., Keramidas, I., Antoniou, C., Deidun, A., Font, T., Kleitou, P., Lloret, J., Matić-Skoko, S., Said, A., Tiralongo, F., Moutopoulos, D.K., 2018. Identifying recreational fisheries in the Mediterranean Sea through social media. Fish. Manag. Ecol. 25 (4), 287–295. https://doi.org/10.1111/fme.12293.

Gómez, S., Riera Aragó, V., 2007. Paisatge, pescadors i peixos: la pesca artesanal al Cap de Creus. Annals de l'Institut d'Estudis Empordanesos 473–489.

Gómez, S., Carreño, A., Lloret, J., 2021. Cultural heritage and environmental ethical values in governance models: conflicts between recreational fisheries and other maritime activities in Mediterranean marine protected areas. Mar. Pol. 129, 104529 https://doi.org/10.1016/j.marpol.2021.104529.

Gori, A., Rossi, S., Berganzo, E., Lluis, J., Mark, P., Gili, J., 2011. Spatial distribution patterns of the gorgonians Eunicella singularis , Paramuricea clavata , and leptogorgia sarmentosa (cape of Creus , northwestern Mediterranean Sea). Mar. Biol. 158, 143–158. https://doi.org/10.1007/s00227-010-1548-8.

Gori, A., Bavestrello, G., Grinyó, J., Dominguez, C., Ambroso, S., Bo, M., 2017. Marine Animal Forests. https://doi.org/10.1007/978-3-319-17001-5. Marine Animal Forests.

Griffiths, J.R., Kadin, M., Nascimento, F.J.A., Tamelander, T., Törnroos, A., Bonaglia, S., Bonsdorff, E., Brüchert, V., Gårdmark, A., Järnström, M., Kotta, J., Lindegren, M., Nordström, M.C., Norkko, A., Olsson, J., Weigel, B., Žydelis, R., Blenckner, T., Niiranen, S., Winder, M., 2017. The importance of benthic–pelagic coupling for marine ecosystem functioning in a changing world. Global Change Biol. 23 (6), 2179–2196. https://doi.org/10.1111/gcb.13642.

Grinyó, J., Gori, A., Ambroso, S., Purroy, A., Calatayud, C., Dominguez-Carrió, C., Coppari, M., Lo Iacono, C., López-González, P.J., Gili, J.M., 2016. Diversity, distribution and population size structure of deep Mediterranean gorgonian assemblages (Menorca Channel, Western Mediterranean Sea). Prog. Oceanogr. 145, 42–56. https://doi.org/10.1016/j.pocean.2016.05.001.

Grinyó, J., Gori, A., Greenacre, M., Requena, S., Canepa, A., Lo Iacono, C., Ambroso, S., Purroy, A., Gili, J.M., 2018. Megabenthic assemblages in the continental shelf edge and upper slope of the Menorca Channel, Western Mediterranean Sea. Prog.

Oceanogr. 162 (November 2016), 40–51. https://doi.org/10.1016/j.pocean.2018.02.002.
Grinyó, J., Lo Iacono, C., Pierdomenico, M., Conlon, S., Corbera, G., Gràcia, E., 2020. Evidences of human impact on megabenthic assemblages of bathyal sediments in the Alboran Sea (western Mediterranean). Deep Sea Res. Oceanogr. Res. Pap. 165, 103369 https://doi.org/10.1016/j.dsr.2020.103369.
Henseler, C., Nordström, M.C., Törnroos, A., Snickars, M., Pecuchet, L., Lindegren, M., Bonsdorff, E., 2019. Coastal habitats and their importance for the diversity of benthic communities: a species- and trait-based approach. Estuar. Coast Shelf Sci. 226, 106272 https://doi.org/10.1016/J.ECSS.2019.106272.
Komsta, L., Novomestky, F., 2012. Moments, Cumulants, Skewness, Kurtosis and Related Tests. R Package Version 0.13. https://CRAN.R-project.org/package=moments.
Kritzer, J.P., DeLucia, M.B., Greene, E., Shumway, C., Topolski, M.F., Thomas-Blate, J., Chiarella, L.A., Davy, K.B., Smith, K., 2016. The importance of benthic habitats for coastal fisheries. Bioscience 66 (4), 274–284. https://doi.org/10.1093/BIOSCI/BIW014.
Kupfner Johnson, S., Hallock, P., 2020. A review of symbiotic gorgonian research in the western Atlantic and Caribbean with recommendations for future work. Coral Reefs 39 (2), 239–258. https://doi:10.1007/s00338-020-01891-0.
Linares, C., Coma, R., Garrabou, J., Díaz, D., Zabala, M., 2008. Size distribution, density and disturbance in two Mediterranean gorgonians: Paramuricea clavata and Eunicella singularis. J. Appl. Ecol. 45, 688–699. https://doi.org/10.1111/j.1365-2664.2007.01419.x.
Link, J., Segal, B., Miguel, L., 2019. Abandoned, lost or otherwise discarded fishing gear in Brazil: a review. Perspect. Ecol. Conserv. 17, 1–8. https://doi.org/10.1016/j.pecon.2018.12.003.
Lloret, J., Zaragoza, N., Caballero, D., Riera, V., 2008. Biological and socioeconomic implications of recreational boat fishing for the management of fishery resources in the marine reserve of Cap de Creus (NW Mediterranean). Fish. Res. 91 (2–3), 252–259. https://doi.org/10.1016/j.fishres.2007.12.002.
Lloret, J., Casadevall, M., Muñoz, M., 2010. Seguiment de la pesca recreativa al Parc Natural de Cap de Creus Estudi 2009.
Lo Iacono, C., Orejas, C., Gori, A., Gili, J.M., Requena, S., Puig, P., Ribó, M., 2012. 32 Habitats of the Cap de Creus Continental Shelf and Cap de Creus Canyon , Northwestern Mediterranean. https://doi.org/10.1016/B978-0-12-385140-6.00032-3.
Lo Iacono, C., Grinyó, J., Conlon, S., Lafosse, M., Rabaute, A., Pierdomenico, M., Perea, H., d'Acremont, E., Gràcia, E., 2020. Near-pristine benthic habitats on the francesc pagès bank, alboran sea, western mediterranean. Seafloor Geomorphology as Benthic Habitat 889–901. https://doi.org/10.1016/b978-0-12-814960-7.00055-5.
Lokrantz, J., Nyström, M., Norström, A.V., Folke, C., Cinner, J.E., 2010. Impacts of artisanal fishing on key functional groups and the potential vulnerability of coral reefs. Environ. Conserv. 36 (4), 327–337. https://doi.org/10.1017/S0376892910000147.
Lotze, H.K., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., Kidwell, S.M., Kirby, M.X., Peterson, C.H., Jackson, J.B.C., 2006. Depletion degradation, and recovery potential of estuaries and coastal seas. Science 312 (5781), 1806–1809. https://doi.org/10.1126/SCIENCE.1128035.
McFadden, C.S., van Ofwegen, L.P., Quattrini, A.M., 2022. Revisionary systematics of Octocorallia (Cnidaria: anthozoa) guided by phylogenomics. Bulletin of the Society of Systematic Biologists 1 (3), 8735, 1-79., available online at: https://ssbbulletin.org/index.php/bssb/article/view/8735.
Montseny, M., Linares, C., Viladrich, N., Biel, M., Gracias, N., Baena, P., Quintanilla, E., Ambroso, S., Grinyó, J., Santín, A., Salazar, J., Carreras, M., Palomeras, N., Magí, L., Vallicrosa, G., Gili, J.M., Gori, A., 2021. Involving Fishers in scaling up the restoration of cold-water coral gardens on the Mediterranean continental shelf. Biol. Conserv. 262, 109301 https://doi.org/10.1016/j.biocon.2021.109301.
Murillo, F.J., Kenchington, E., Koen-Alonso, M., Guijarro, J., Kenchington, T.J., Sacau, M., et al., 2020. Mapping benthic ecological diversity and interactions with bottom-contact fishing on the Flemish Cap (northwest Atlantic). Ecol. Indicat. 112, 106135 https://doi.org/10.1016/j.ecolind.2020.106135.
Navarro-Barranco, C., Ambroso, S., Gerovasileiou, V., Gómez-Gras, D., Grinyó, J., Montseny, M., Santín, A., 2023. Conservation of dark habitats. Coastal Habitat Conservation 147–170. https://doi.org/10.1016/b978-0-323-85613-3.00005-0.
Oksanen, A.J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., Mcglinn, D., Minchin, P.R., Hara, R.B.O., Simpson, G.L., Solymos, P., Stevens, M.H.H., Szoecs, E., 2015. Vegan: Community Ecology Package. R Package Vegan, Vers. 2.2-1. CRAN, January.
Orejas, C., Gori, A., Lo Iacono, C., Puig, P., Gili, J.M., Dale, M.R.T., 2009. Cold-water corals in the Cap de Creus canyon, northwestern Mediterranean: spatial distribution, density and anthropogenic impact. Mar. Ecol. Prog. Ser. 397, 37–51. https://doi.org/10.3354/meps08314 m.
Otero, M.M., Numa, C., Bo, M., Orejas, C., Garrabou, J., Cerrano, C., Kružić, P., Antoniadou, C., Aguilar, R., Kipson, S., Linares, C., Terrón-Sigler, A., Brossard, J., Kersting, D., Casado-Amezúa, P., García, S., Goffredo, S., Ocaña, O., Caroselli, E., Maldonado, M., Bavestrello, G., Cattaneo-Vietti, R., Özalp, B., 2017. Overview of the Conservation Status of Mediterranean Anthozoans. IUCN, Malaga, Spain. https://doi.org/10.2305/iucn.ch.2017.ra.2.en x + 73.
Petović, S., Marković, O., Đorđević, N., 2021. Macrozoobenthic species as a part of the benthic communities along the Montenegrin adriatic coast. Handb. Environ. Chem. 109, 153–191. https://doi.org/10.1007/698_2021_755.
Pham, C.K., Diogo, H., Menezes, G., Porteiro, F., Braga-Henriques, A., Vandeperre, F., Morato, T., 2014. Deep-water longline fishing has reduced impact on Vulnerable Marine Ecosystems. Sci. Rep. 4 (1), 1–6. https://doi.org/10.1038/srep04837, 2014 4:1.
Pikitch, E.K., Santora, C., Babcock, E.A., Bakun, A., Bonfil, R., Conover, D.O., Dayton, P., Doukakis, P., Fluharty, D., Heneman, B., Houde, E.D., Link, J., 2004. Ecosystem-based fishery management. Science 305 (5682), 346–347. https://doi.org/10.1126/science.1098222.
Purroy, A., Requena, S., Gili, J.M., Canepa, A., Sardá, R., 2014. Spatial assessment of artisanal fisheries and their potential impact on the seabed: the Cap de Creus regional case study (northwestern Mediterranean Sea). Sci. Mar. 78 (4), 449–459. https://doi.org/10.3989/scimar.04000.21a.
Quintanilla, E., Gili, J., López-gonzález, P.J., Tsounis, G., Madurell, T., Fiorillo, I., Rossi, S., 2013. Sexual reproductive cycle of the epibiotic soft coral Alcyonium coralloides (Octocorallia , Alcyonacea). Aquat. Biol. 18, 113–124. https://doi.org/10.3354/ab00493.
Roberts, D.W., 2019. Package ' Labdsv '. Ordination and Multivariate Analysis for Ecology. CRAN.
Rufino, M.M., Pereira, A.M., Pereira, F., Moura, P., Vasconcelos, P., Gaspar, M.B., 2017. Habitat structure shaping megabenthic communities inhabiting subtidal soft bottoms along the Algarve coast (Portugal). Hydrobiologia 784 (1), 249–264. https://doi.org/10.1007/S10750-016-2879-3.
Santín, A., Grinyó, J., Ambroso, S., Uriz, M.J., Dominguez-Carrió, C., Gili, J.M., 2019. Distribution patterns and demographic trends of demosponges at the Menorca Channel (northwestern Mediterranean Sea). Prog. Oceanogr. 173, 9–25. https://doi.org/10.1016/j.pocean.2019.02.002.
Santín, A., Grinyó, J., Ambroso, S., Baena, P., Biel-Cabanelas, M., Corbera, G., Salazar, J., Montseny, M., Gili, J.M., 2022a. In: Martínez de Albéniz, M.V. (Ed.), Fishermen and Scientists: Synergies for the Exploration, Conservation and Sustainability of the Marine Environment, The Ocean We Want: Inclusive and Transformative Ocean Science. Institut de Ciències del Mar, CSIC, pp. 77–79. https://doi.org/10.20350/digitalCSIC/14070.
Santín, A., Grinyó, J., Aguzzi, J., Ambroso, S., Baena, P., Bahamon, N., Biel-Cabanelas, M., Chatzievangelou, D., Company, J.B., Corbera, G., García del Arco, J. A., Gómez, M., Gori, A., Gutiérrez, V., Linares, C., Montseny, M., Navarro, J., Recasens, L., Rotllant, G., Salazar, J., García Varas, J.L., Gili, J.M., Girona's territorial federation of fishers' guilds, 2022b. Ecological restoration of human-impacted mediterranean benthic marine ecosystems through active strategies and participatory approach: the life project ECOREST. Proceedings of the 3rd Mediterranean Symposium on the Conservation of the Dark Habitats 1, 80–85.
Sardá, R., Requena, S., Dominguez-Carrió, C., Gili, J.M., 2017. Ecosystem-based management for marine protected areas. In: Goriup, P.D. (Ed.), Management of Marine Protected Areas. https://doi.org/10.1002/9781119075806.ch8.
Sini, M., Kipson, S., Linares, C., Koutsoubas, D., Garrabou, J., 2015. The yellow gorgonian Eunicella cavolini: demography and disturbance levels across the Mediterranean Sea. PLoS One 10 (5). https://doi.org/10.1371/journal.pone.0126253.
Snelgrove, P.V.R., 1997. The importance of marine sediment biodiversity in ecosystem processes. Ambio 26 (8), 578–583.
Tsounis, G., Martinez, L., Bramanti, L., Viladrich, N., Gili, J.M., Martinez, Á., Rossi, S., 2012. Anthropogenic effects on reproductive effort and allocation of energy reserves in the Mediterranean octocoral Paramuricea clavata. Mar. Ecol. Prog. Ser. 449, 161–172. https://doi.org/10.3354/meps09521.
Weinberg, S., 1979a. Autecology of shallow-water octocorallia from mediterranean rocky substrata, I. The banyuls area. Bijdr. Dierkd. 49 (1), 1–15. https://doi.org/10.1163/26660644-04901001.
Weinberg, S., 1979b. The light-dependent behaviour of planula larvae of Eunicella singularis and Corallium rubrum and its implication for octocorallian ecology. Bijdragen Lot de Dierkunde 49 (1), 16–30.