








Article

Recovery Signals of Rhodoliths Beds since Bottom Trawling Ban in the SCI Menorca Channel (Western Mediterranean)

Maria Teresa Farriols ^{1,*}, Camille Irlinger ^{1,2}, Francesc Ordines ¹, Desirée Palomino ³, Elena Marco-Herrero ⁴, Javier Soto-Navarro ⁵, Gabriel Jordà ¹, Sandra Mallol ¹, David Díaz ¹, Natalia Martínez-Carreño ³, Julio A. Díaz ¹, Ulla Fernandez-Arcaya ⁶, Sergi Joher ¹, Sergio Ramírez-Amaro ¹, Nuria R. de la Ballina ¹, Juan-Tomás Vázquez ³ and Enric Massutí ¹

- ¹ Centre Oceanogràfic de les Balears, Instituto Español de Oceanografía (IEO-CSIC), 07015 Palma, Spain; camille.irlinger@gmail.com (C.I.); xisco.ordinas@ieo.es (F.O.); gabriel.jorda@ieo.es (G.J.); sandra.mallol@ieo.es (S.M.); david.diaz@ieo.es (D.D.); julio.diaz@ieo.es (J.A.D.); sergi.joher@ieo.es (S.J.); sergio.ramirez@ieo.es (S.R.-A.); nuria.rodriguez@ieo.es (N.R.d.l.B.); enric.massuti@ieo.es (E.M.)
 - ² College of Science and Technology, Unité de Formation des Sciences de la Terre et Environnement, Université de Bordeaux, 33000 Bordeaux, France
 - ³ Centro Oceanográfico de Málaga, Instituto Español de Oceanografía (IEO-CSIC), 29640 Fuengirola, Spain; desiree.palomino@ieo.es (D.P.); natalia.martinez@ieo.es (N.M.-C.); juantomas.vazquez@ieo.es (J.-T.V.)
 - ⁴ Centro Oceanográfico de Cádiz, Instituto Español de Oceanografía (IEO-CSIC), 11006 Cádiz, Spain; elena.marco@ieo.es
 - ⁵ Physical Oceanography Group, University of Málaga (GOFIMA), Campus de Teatinos, 29071 Málaga, Spain; javiersoto@uma.es
 - ⁶ Centro Oceanográfico de Santander, Instituto Español de Oceanografía (IEO-CSIC), 39004 Santander, Spain; ulla.fernandez@ieo.es
- * Correspondence: mt.farriols@ieo.es



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Abstract: One of the objectives of the LIFE IP INTEMARES project is to assess the impact of bottom trawling on the vulnerable benthic habitats of the circalittoral bottoms of the Menorca Channel (western Mediterranean), designated a Site of Community Importance (SCI) within the Natura 2000 network. The present study compares the epibenthic communities of four areas, subjected to different bottom trawl fishing intensity levels. The assignment of fishing effort levels was based on the fishing effort distribution in the area calculated from Vessel Monitoring System (VMS) data and the existence of two Fishing Protected Zones in the Menorca Channel. Biological samples were collected from 39 beam trawl stations, sampled during a scientific survey on April 2019. We compare the diversity, composition, and density of the epibenthic flora and fauna, together with the rhodoliths coverage and the morphology of the main species of rhodoliths of four areas subjected to different levels of bottom trawl fishing effort, including one that has never been impacted by trawling. Our results have shown negative impacts of bottom trawling on rhodoliths beds and the first signals of their recovery in areas recently closed to this fishery, which indicate that this is an effective measure for the conservation of this habitat of special interest and must be included in the management plan required to declare the Menorca Channel as a Special Area of Conservation.

Keywords: community ecology; epibenthic communities; bottom trawling; fishing effort; biodiversity; rhodoliths morphology; rhodoliths size

1. Introduction

Rhodoliths beds are bottoms characterized by the accumulation of calcareous red algae, mainly belonging to the orders Corallinales and Hapalidiales, although some Peyssonneliales can also form rhodoliths [1]. Rhodoliths can move freely on the seabed with water motion and can be composed entirely of a non-geniculate coralline algae (sometimes more than one species) or have a core of other material, sometimes called “nucleated rhodoliths” [2]. Living individuals are found from shallow areas to more than 150 m

depth [3], as long as there is enough light input for their growth [4–6]. Rhodoliths prefer sedimentary bottoms subject to moderate water currents, allowing a rolling movement that eases their growth, prevents burial by sediment, and hinders overgrowth by other algae [7–9].

Rhodoliths-forming species are considered bioengineers [2,10–12], as they increase the structural complexity of the sedimentary bottoms, creating habitats that provide the refuge needed for a wide variety of marine species during key vital stages such as settlement and nursing [12–16]. Moreover, rhodoliths beds are one of the main biogenic sources of calcium carbonate on the planet, with a potential role in climate regulation [17]. Even so, different impacts, such as rhodoliths extraction, fishing, aquaculture, pollution, invasive species, and the combined pressures of ocean warming and acidification, endanger this habitat and its important biological and physico-chemical role [2,10,16,18,19].

Fishing activities, attracted by the presence of valuable commercial species on these rhodoliths beds, cause a series of direct and indirect impacts on this habitat [10,20–22]. The presence of those species focuses the fishery activity, and also results in a high proportion of rhodoliths extracted as discards, mostly by bottom trawl fishery [23,24]. Bottom trawling is particularly harmful due to the direct extraction of rhodoliths causing direct physical damage, including breakage of thalli as well as abrasion and dispersion of rhodoliths [25]. Besides, sediment re-suspended by bottom trawling, once settled, can bury rhodoliths, causing high mortalities due to light being unable to reach the algae, plus photosynthetic activity is stopped at the same time that smothering with fine sediments may limit the gaseous exchange needed by the algae to survive [5]. The resulting reductions in biomass and diversity of rhodolith species, as well as the shift in the biological communities of rhodoliths beds, favor opportunistic species that do not require a stable environment to develop [10,26].

The pronounced oligotrophy of the waters around the Balearic Islands (western Mediterranean), along with a dry climate, the reduced watershed areas, the karstic nature of most of the islands favoring rapid infiltration of rainfall, and the lack of river runoff, explains the high transparency of the waters in the area that enables algal populations to grow until 90–100 m depth [27,28]. Red algae beds, with two main communities being rhodoliths and *Peyssonnelia* beds, dominate the coastal continental shelf landscape down to 85 m depth, overlapping with the traditional fishing grounds of the bottom trawl fleet [29,30].

The Menorca Channel is an area approximately 36 km wide, located between Mallorca and Menorca islands, in the northeastern part of the Balearic Promontory, which corresponds to a northeast prolongation of the Betics (Figure 1) [31]. It represents almost 20% of the surface of the continental shelf around these islands. The seafloor has a smooth regular relief, until the continental shelf edge at 120–150 m, where it sharply deepens [31,32]. It shows high environmental heterogeneity, due to the occurrence of rocky beds, and detrital sediments as sandy shores and gravel beds. Sediments are mainly composed by sand and gravel, with high carbonate content [33]. The area is affected by strong northerly winds and offshore currents [34,35].

The Menorca Channel presents a wide distribution of species and habitats of conservation interest, such as coralligenous platforms, rhodoliths beds, and biogenic detritic bottoms [36,37]. Due to this, in 2014 it was designated a Site of Community Importance (SCI) within the Natura 2000 network, covering an area around 1674 km² and, consequently, it has to be declared a Special Area of Conservation (SAC). This protection regime seeks to ensure long-term preservation of the area as well as its flora and fauna, as well as the sustainability of human activities carried out therein, through the implementation of management plans. In 2016, two Fishing Protected Zones (FPZ) were also declared in a smaller area of the Menorca Channel, where the trawl fleet was excluded; this was as a result of the implementation of the Council Regulation (EC) N° 1967/2006, concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, which considers the rhodoliths and coralligenous beds as protected habitats and prohibits the bottom trawling and other benthic fishing gears over these bottoms.

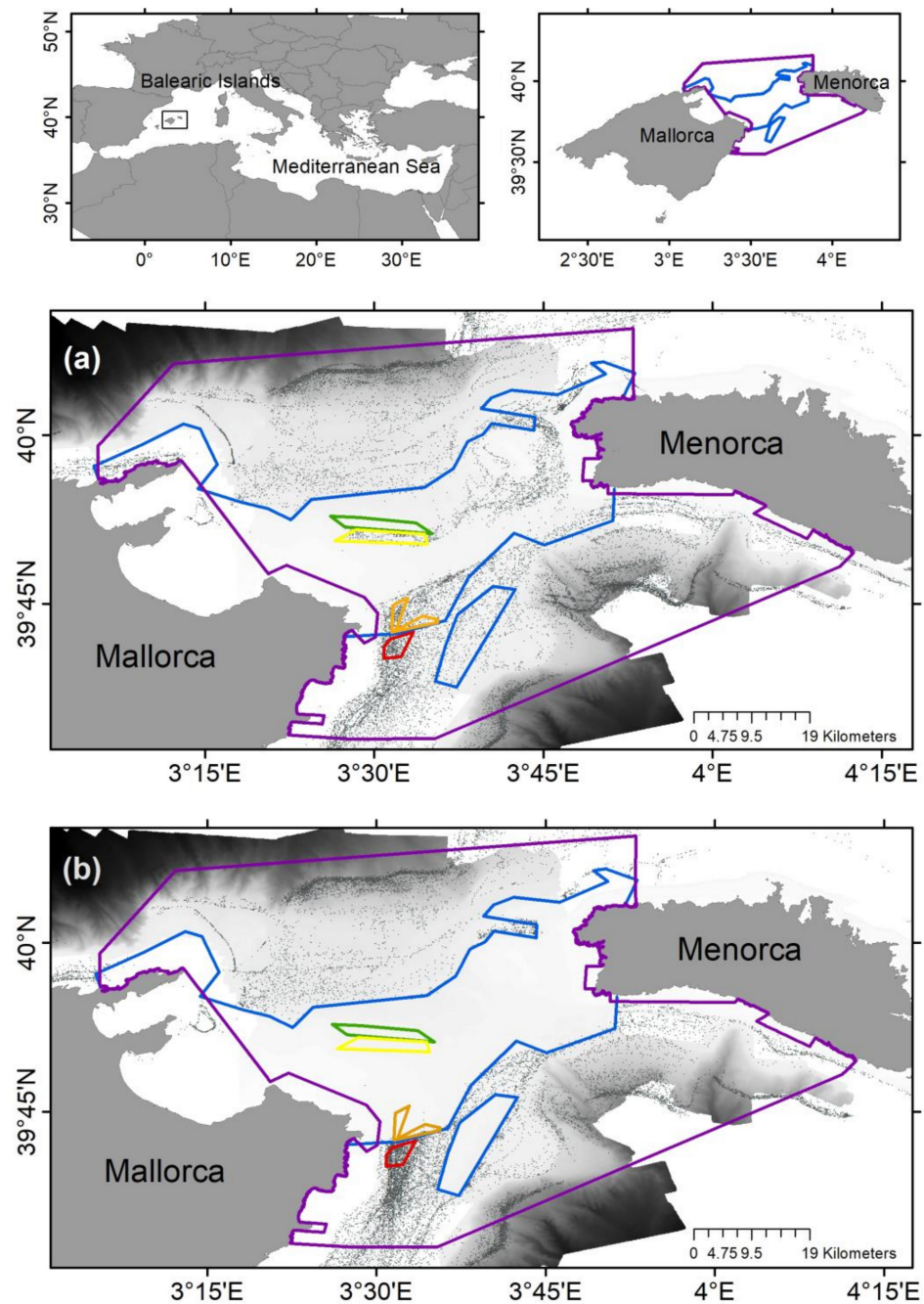


Figure 1. Map of the Menorca Channel (Balearic Islands, western Mediterranean) showing the Site of Community Importance (SCI; in lilac) and the trawl Fishing Protected Zones (in blue), declared in 2014 and 2016, respectively. The signals from the Vessel Monitoring System (VMS) during the periods: (a) 2014–2015 and (b) 2017–2018 are represented. The four areas with different levels of bottom trawl fishing effort (Non-Impacted: green; Low effort history: yellow; Medium effort history: orange; High effort: red) compared in the present study are also shown.

Scientific information about the impact of fishing activities on rhodoliths and coral-ligenous beds is needed in the area to develop the management plan required for the designation of the Menorca Channel as an SAC. So far, the only information about these activities in the Menorca Channel are the study developed by Moranta et al. [38] within the framework of the LIFE+ INDEMARES project (<https://www.indemares.es/en>; accessed on 31 October 2021), with inconclusive results in relation to the effect of bottom trawling on rhodoliths beds, and the results of the ECOSAFIMED project (<https://ecosafimed.eu/>; ac-

cessed on 31 October 2021) suggesting reductions in percentages of biogenic substrates and richness of megabenthic species due to the effects of impacts of artisanal fishery (trammel nets) on coralligenous beds.

The current study was developed within the framework of the LIFE IP INTEMARES project (<https://intemares.es/en>; accessed on 31 October 2021) and aims to assess the effects of bottom trawling on the rhodoliths beds of the SCI Menorca Channel. To do so, we compare the diversity, composition, and density of the epibenthic flora and fauna, together with the rhodoliths coverage and the morphology of the main species of rhodoliths of the four areas subjected to different levels of bottom trawl fishing effort, including one that has never been impacted by trawling.

2. Materials and Methods

A scientific survey was conducted from 21 April 2019 to 10 May 2019 onboard the R/V *Angeles Alvariño*. During this survey, data and samples were collected to characterize and compare the bathymetry of the seafloor, sediments, and epibenthic flora and fauna in the four areas subjected to different levels of bottom trawl fishing pressure. Data related to hydrodynamics conditions and fishing activity in the study area have also been used.

2.1. Sampling Strategy

Areas with different levels of bottom trawl fishing effort were selected by using the information collected through the Vessel Monitoring System (VMS) in the area. Two periods were considered, 2014–2015 and 2017–2018, before and after the declaration of two Fishing Protected Zones (FPZ) in the Menorca Channel in 2016 (BOE A-2016-8512 Orden AAA/1479/2016). VMS data consist of position and instantaneous velocity that each fishing vessel sends automatically via satellite communications every two hours. Data generated during navigation were excluded from the analyses, by considering only VMS signals with instantaneous velocities ranging from 2 to 3.6 knots, which is the towing speed used by trawlers in the area [30]. A map with filtered VMS signals was created in order to estimate the fishing effort in the study area before and after the declaration of the FPZ (Figure 1).

Considering differences in bottom trawl fishing effort, four sampling areas were identified: (i) Non-Impacted: area that has never been subject to bottom trawl fishing activity; (ii) Low effort history: area placed within the FPZ previously subjected to low level of fishing effort; (iii) Medium effort history: area placed within the FPZ previously subjected to a high level of fishing effort; and (iv) High effort: area subjected to a high level of fishing effort until nowadays (not included in the FPZ). The mean number of fishing trips in each of these areas during the period 2014–2015, estimated from VMS data were 0, 77, 125, and 148 for Non-impacted, Low effort history, Medium effort history, and High effort, respectively. During 2017 and 2018, the High effort area registered 218 fishing trips, whereas the effort was null in the remaining areas.

2.2. Bathymetry and Sediment Characterization

The bathymetric and backscatter data were acquired with the EM710 multibeam echosounder, transmitting from 70 to 100 kHz. During the acquisition, a sound velocity correction was applied using a SV Plus profiler. Bathymetric and backscatter data were integrated into a GIS software (ArcGIS v.10.8), where bathymetry-derived maps, as slope and orientation, were obtained with a 1 m grid resolution (Figure 2).

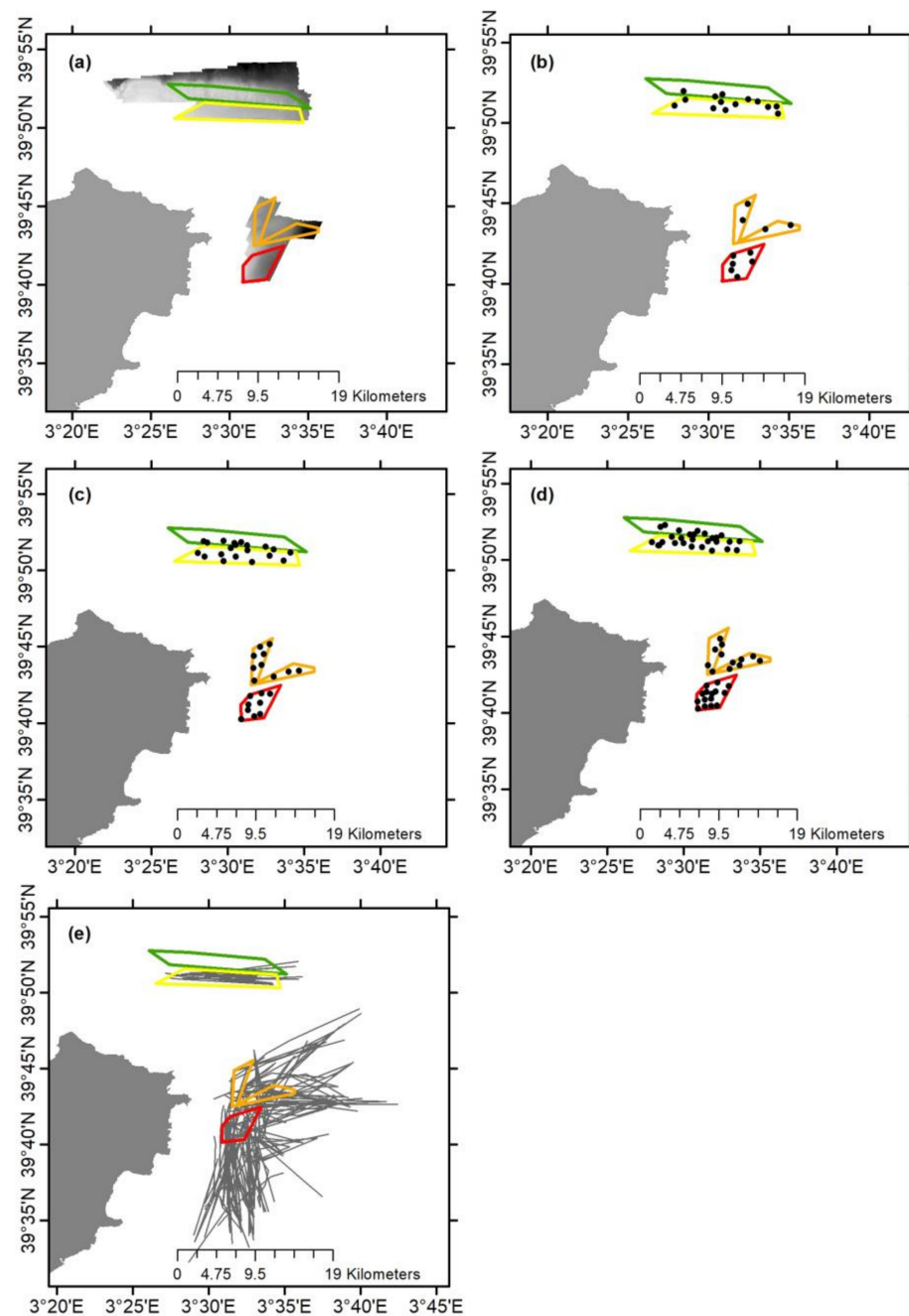


Figure 2. Map of the Menorca Channel (Balearic Islands, western Mediterranean) showing the location of sampling stations: (a) bathymetry-derived maps; (b) samples collected with Shipek dredge; (c) samples collected with beam trawl; (d) video transects made with TASIFE photogrammetric sledge; and (e) commercial hauls of the trawling fleet sampled from observers onboard. The four areas with different levels of bottom trawl fishing effort (Non-Impacted: green; Low effort history: yellow; Medium effort history: orange; High effort: red) compared in the present study are also shown.

Up to 24 samples, (3, 10, 4, and 7 for Non-impacted, Low effort history, Medium effort history, and High effort areas, respectively) for grain-size analysis of superficial sediments were collected with a Shipek dredge (Figure 2). Once onboard, samples were frozen at $-20\text{ }^{\circ}\text{C}$ and saved for posterior laboratory analysis. In the laboratory, these samples were dried at $60\text{ }^{\circ}\text{C}$ and introduced in a 10% solution of hydrogen peroxide during 24 h and after that into a 20% solution of hydrogen peroxide during 24 h more, in order to remove the organic matter. A 2% solution of sodium polyphosphate was added during 24 h more, in

order to stimulate sample dispersion. Then, samples were dried during 24–48 h at 60 °C. The proportion of gravel, sand, and mud of each sample was obtained after sieved with a column of 2, 1, 0.5, 0.25, 0.125 and 0.063 mm plates. The classification of the sediments was based on Folk [39] ternary diagrams, and the GRADISTAT program was also used.

2.3. Epibenthic Communities

Samples of epibenthic species were obtained during the survey using a standard beam trawl described by Jennings et al. [40], for which the efficiency has been estimated by Reiss et al. [41]. This beam trawl has horizontal and vertical openings of 2 and 0.5 m, respectively, with a codend mesh size of 5 mm. The number of samples was 9, 11, 10, and 9 in Non-impacted, Low effort history, Medium effort history, and High effort areas, respectively (Figure 2). They were collected at a speed of 2 knots, with an effective sampling duration that never exceeded 5 min. The depth of each sample was estimated by a SCANMAR sensor, and the position and velocity of the vessel during the sampling operations were obtained from a Seapath 500 positioning system.

Once the samples were onboard, species were sorted, identified to the lowest possible taxonomic level, counted and weighed. The abundance (n) and biomass (kg) of each species or taxon was standardized to 1000 m², by calculating the area covered in each haul using the initial and final position as well as the horizontal opening of the beam trawl. Pelagic species were excluded from the analyses.

Up to 15 live individuals belonging to three rhodoliths species, *Lithothamnion valens*, *Spongites fruticulosus*, and *Phymatolithon calcareum*, were randomly collected from each sample. The longest axis of each rhodolith was measured onboard and the individual was photographed and saved. In the laboratory, the area of each rhodolith was also measured using the ImageJ[®] program (<https://imagej.nih.gov/ij/>; accessed on 31 October 2021) [42].

2.4. Visual Observations

Up to 53 video transects of the seafloor were obtained during the survey with the TASIFE photogrammetric sledge (Figure 2). The transects were carried out with the vehicle moving at 0.5 knots and flying between 1 and 2 m above the bottom. Each video transect had a mean duration of 15 min, with a minimum distance of 50 m between transects. The number of transects was 13, 15, 10, and 15 in Non-impacted, Low effort history, Medium effort history, and High effort areas, respectively.

Video images were used to calculate rhodoliths coverage of each sampled area. VLC Media Player 3.0.8 Windows 10 software was used to visualize and analyze video transects in the laboratory. Sequences with poor image quality or too far away from the seafloor were considered unsuitable, the video sequences validated as correct were divided into scenes with equal distance from the seafloor, and the percentage coverage of different types of seabed substrate found was estimated. The distance covered by each transect was calculated with geographically referenced data obtained from Hypack 2018 using GIS (QGIS 3.20.3) synchronized with the time of the video. The area covered was obtained from the transect distance and the distance between two laser points of the sledge.

2.5. Hydrodynamic Conditions

Due to the lack of suitable observations, the currents in the region have been characterized using the outputs of a state-of-the-art numerical model. Model velocity fields in the study area were retrieved from the Western Mediterranean Operational forecasting system (WMOP), developed and operated by the Balearic Islands Coastal Observing and Forecasting System (SOCIB; <http://www.socib.eu/>; accessed on 31 October 2021). WMOP is a configuration of the Regional Ocean Modeling System (ROMS) [43] adapted to the western Mediterranean. Its domain covers from the Strait of Gibraltar to the Sardinia Channel, with a spatial resolution of 1.8–2.2 km and 32 stretched sigma vertical levels. More details about the boundary conditions, the atmospheric and river run-off forcing, and the assimilation of sea level, water temperature, and salinity data through a local multi-model

ensemble optimal interpolation scheme can be found in Juza et al. [44], Mourre et al. [45], and Hernandez-Lasheras and Mourre [46].

Daily velocity currents data from August 2016 to March 2020, covering the region of the Menorca Channel, were retrieved from the SOCIB data repository. Then, the model near-bottom velocities were interpolated to the initial and final positions of each beam trawl sample, while the mean, the 5th, and the 95th percentiles of the velocity components were computed to characterize the near-bottom velocity at each of the beam-trawl positions. Mean values of velocity components and module between the initial and final beam-trawl positions were calculated.

2.6. Data Analysis

Diversity indices such as species richness (S), Shannon's diversity index (H'), and Pielous's evenness (J') of the epibenthic communities were calculated from the beam trawl samples. The N_{90} index is based on the SIMPER analysis that quantifies the contribution of each species to the within-group similarity in a group of samples based on the Bray–Curtis similarity index [47,48]. N_{90} represents the number of species that contributes up to 90% to within-group similarity in SIMPER analysis and has been calculated following the procedure described in Farriols et al. [49]. The samples were grouped according to the four sampled areas (Non-impacted, Low effort history, Medium effort history and High effort).

For each area (level of fishing effort), we calculated the mean values, with their standard errors, of the standardized abundance and biomass of the whole epibenthic communities, their main taxonomic groups, and the diversity indices mentioned above.

Based on the rhodoliths measures explained in Section 2.3, two morphological variables were calculated:

- Size: longest axis of each rhodolith.
- Roundness (R): used as a proxy of the sphericity of rhodoliths. Results measured range from 0 (elongated shape) to 1 (circle shape). It was calculated as follows:

$$R = 4 \times \frac{[area]}{\pi [longest\ axis]^2}. \quad (1)$$

The mean values of standardized biomass, size, and roundness, with their standard errors, of *L. valens*, *S. fruticulosus*, and *P. calcareum* were calculated in each of the four areas considered.

A multivariate composed multidimensional scaling (MDS) analysis was applied to standardized abundances of species of beam trawl samples with PRIMER 7 [50]. This analysis allows for linking multivariate environmental patterns to the MDS based on species composition of samples. For multivariate analysis, data were square-root transformed and the similarity between samples was calculated using the Bray–Curtis index. The explanatory variables considered were, depth, slope, backscatter, and orientation of the seafloor, as well as horizontal and vertical components of velocity currents in the bottom and the velocity module. The characteristics of sediments have not been included in the model because sediment samples associated to each beam trawl sample were not available. The environmental variables represented on the MDS were selected to maximize the Spearman rank correlation between species composition and environmental patterns with the BEST routine in PRIMER 7 [50]. For environmental data, similarity between samples was calculated using the Euclidian distance.

Student's t -test was applied to test for differences in abundances and biomass of main taxonomic groups and diversity indices of the epibenthic assemblages in these areas, as well as to compare biomass, size, and roundness of the three species of rhodoliths considered and their coverage. Prior to the use of the t -test, the Shapiro–Wilk test was applied to check for normality. When this assumption was not met, a Kruskal–Wallis non-parametric test was applied.

2.7. Trawl Fishery

The species composition of the captures of the bottom trawl fleet was determined in order to assess the catchability of the species present in the study area. Biomass and abundance of epibenthic and nektobenthic organisms removed by the bottom trawlers were quantified using data collected by scientific observers onboard this fleet. In this case, and due to bottom trawlers covering high distances that range from 2.8 to 20.3 km in the area, we were not able to separate data from Medium effort history and High effort areas, so they were grouped together (Figure 2).

A total of 53 commercial hauls carried out in the SCI Menorca Channel fishing grounds between 2001 and 2015 were analyzed. That period was taken into account because all the areas except the Non-impacted were trawled during this period and it considered a large enough number of samples in the Low effort history area. The number of hauls analyzed in these two areas was 6 and 45, respectively, with a mean depth of 65 and 59 m. The data collected included position, vessel speed, and depth, along with the number of specimens as well as the weight of retained and discarded catches. Biomass and abundance of species or commercial categories were standardized to 30 min of fishing.

3. Results

3.1. Environmental Variables

The results of seafloor bathymetry, grain size sediment characterization, and bottom currents velocity in the four studied areas are shown in Table 1. Depth and slope of the seafloor showed higher values in Non-impacted and Low effort history areas than in Medium effort history and High effort areas, while backscatter showed lower values in Non-impacted and Low effort history areas than in Medium effort history and High effort areas. Sediments showed a higher proportion of gravel in Medium effort history and High effort areas than in Non-impacted and Low effort history areas, while the proportion of sand was lower in Medium effort history and High effort areas than in Non-impacted and Low effort history areas. Bottom currents showed similar values of horizontal, vertical and velocity module in Non-impact and Low effort history areas compared to Medium effort history and high effort areas.

Table 1. Average values (\pm standard deviations) of environmental variables estimated on each of the four study areas with different levels of bottom trawl fishing effort at the SCI Menorca Channel (Balearic Islands, western Mediterranean). u and v are the horizontal and vertical components of velocity currents, respectively, and $|v|$ is the velocity module.

Variables		Non-Impact	Low Effort History	Medium Effort History	High Effort
Seafloor bathymetry	Depth (m)	70.3 \pm 2.1	70.4 \pm 2.9	59.4 \pm 2.5	58.1 \pm 2.1
	Slope ($^{\circ}$)	0.6 \pm 0.2	0.4 \pm 0.1	0.3 \pm 0.1	0.2 \pm 0.1
	Backscatter (dB)	−20.8 \pm 2.7	−23.1 \pm 2.8	−18.9 \pm 2.5	−18.9 \pm 1.8
	Orientation ($^{\circ}$)	138.1 \pm 36.6	145.0 \pm 27.8	157.2 \pm 45.7	125.9 \pm 19.2
Sediments	Gravel (%)	2.3 \pm 1.9	2.8 \pm 1.6	6.4 \pm 5.0	9.9 \pm 11.2
	Sand (%)	97.0 \pm 2.2	96.7 \pm 1.5	92.8 \pm 5.4	89.5 \pm 11.4
	Mud (%)	0.7 \pm 0.3	0.5 \pm 0.2	0.8 \pm 0.4	0.6 \pm 0.2
Bottom currents	u (cm/s)	1.0 \pm 0.3	1.0 \pm 0.3	0.8 \pm 0.3	−0.2 \pm 0.3
	v (cm/s)	−2.4 \pm 0.4	−2.4 \pm 0.6	−3.6 \pm 0.2	−2.5 \pm 0.4
	$ v $ (cm/s)	3.1 \pm 0.3	3.1 \pm 0.4	3.7 \pm 0.2	2.4 \pm 0.5

The MDS results showed that samples of the four compared areas, grouped into samples located in the center part of the Menorca Channel (Non-impacted and Low effort history areas) and samples located in the southern part (Medium effort history and High effort areas), coincided with changes in environmental factors (Figure 3). Samples from Non-impacted and the adjacent Low effort history area showed a lower similarity between

them than samples from Medium effort history and the adjacent High effort area (Figure 3). The environmental factors with a higher Spearman rank correlation with the species composition were depth, slope, backscatter, and the horizontal and vertical velocity components ($\rho = 0.453$; Figure 3). Results of previous work in the area suggest that environmental conditions are more relevant than fishing effort in the distribution and composition of the epibenthic communities on the continental shelf of the Menorca Channel [38]. Considering the differences in environmental variables as well as the distance between areas located in the center part of the Menorca Channel and areas located in the southern part, plus the fact that the effects of bottom trawling could be difficult to distinguish from that of environmental conditions, we have compared separately the results of Non-impacted and the adjacent Low effort history area and Medium effort history and the adjacent High effort area.

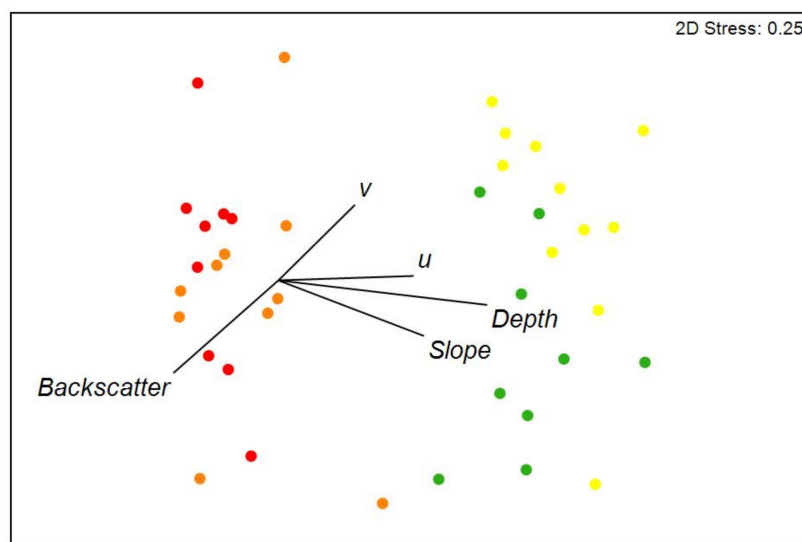


Figure 3. Results of the composed Multidimensional Scaling (MDS) showing the ordination of beam trawl samples according to environmental variables analyzed (depth, slope, and backscatter of the seabed and horizontal (u) and vertical (v) components of bottom currents). Samples from Non-impacted, Low effort history, Medium effort history, and High effort areas are in green, yellow, orange, and red, respectively.

3.2. Epibenthic Communities

In the central part of the Menorca Channel, higher abundance of ascidians was found in Non-impacted (235 ± 44 individuals/1000 m²) compared to Low effort history area (119 ± 19 individuals/1000 m²; Figure 4). Higher abundance of sponges was also found in Non-impacted than in Low effort history areas: 101 ± 26 vs. 41 ± 12 individuals/1000 m² (Figure 4). Rhodoliths biomass in Non-impacted area (210.7 ± 66.5 kg/1000 m²) was higher than in Low effort history area (64.2 ± 20.8 kg/1000 m²; Figure 5). All the diversity indices estimated showed higher values in Non-impacted than in Low effort history area (Figure 6): N_{90} (36.3 ± 0.44 vs. 19.1 ± 0.3 species), S (63.2 ± 1.8 vs. 51 ± 4.6 species), H' (3.52 ± 0.05 vs. 2.73 ± 0.19) and J' (0.85 ± 0.01 vs. 0.69 ± 0.04).

In the southern part of the Menorca Channel, higher abundance of ascidians was found in Medium effort history (311 ± 64 individuals/1000 m²) compared to High effort area (111 ± 18 individuals/1000 m²; Figure 4). Higher values of brown algae biomass were also found in Medium effort history than in High effort area (2.9 ± 1.5 vs. 1.2 ± 0.6 kg/1000 m²; Figure 5). N_{90} was the only diversity index that showed significant differences between Medium effort history and High effort areas with higher values in Medium effort history area (30.3 ± 0.44 vs. 27.6 ± 0.3 species; Figure 6).

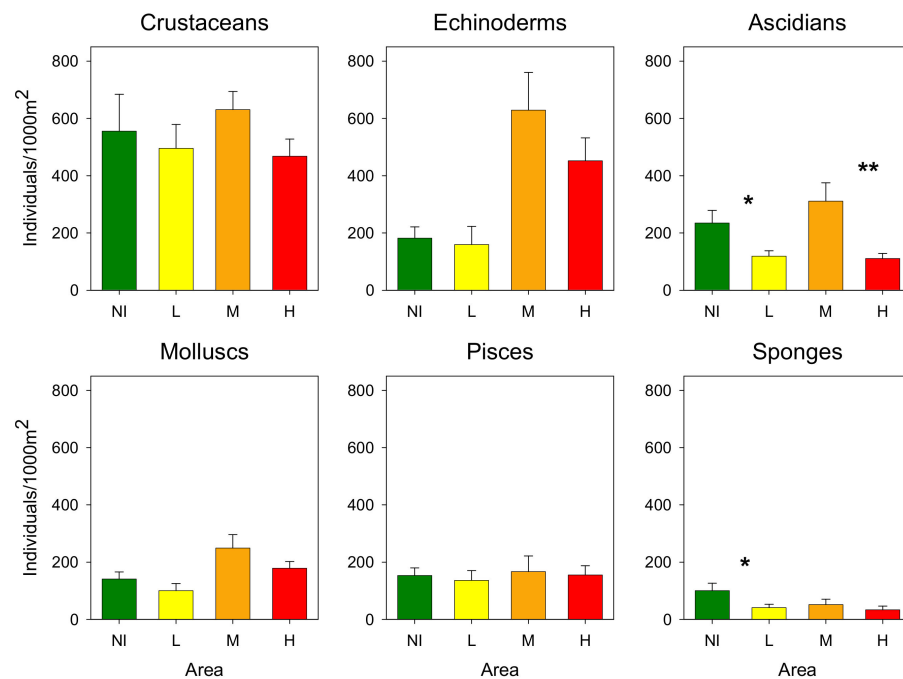


Figure 4. Mean values and standard errors of abundance (individuals/1000 m²) for the main taxonomic groups, estimated from beam trawl samples in the four areas considered: Non-impacted (NI), Low effort history (L), Medium effort history (M), and High effort (H). *p*-values of the Student's *t*-test to test for differences between areas are presented: * *p* < 0.05; ** *p* < 0.01; *** *p* < 0.001.

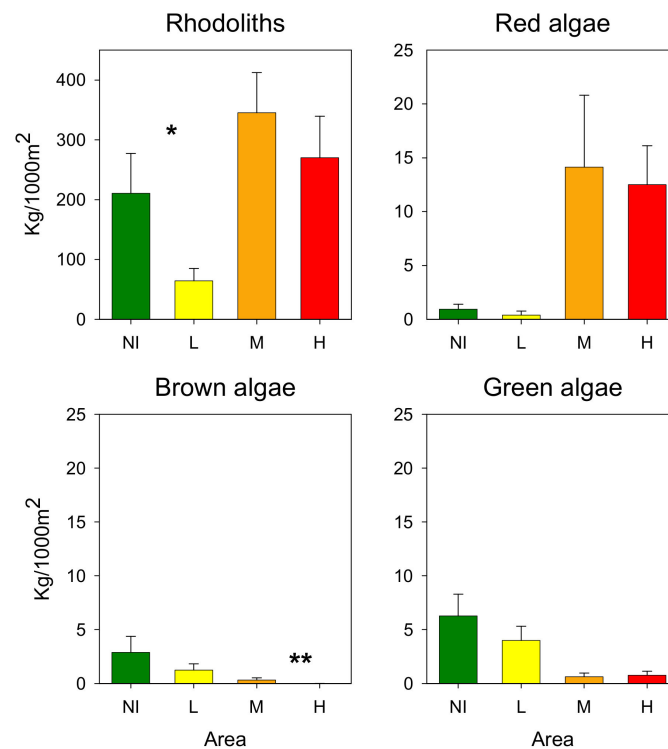


Figure 5. Mean values and standard errors of biomass (kg/1000 m²) for the main groups of algae, estimated from beam trawl samples in the four areas considered: Non-impacted (NI), Low effort history (L), Medium effort history (M), and High effort (H). Red algae are Rhodophytes not included in rhodoliths. *p*-values of the Student's *t*-test to test for differences between areas are presented: * *p* < 0.05; ** *p* < 0.01; *** *p* < 0.001.

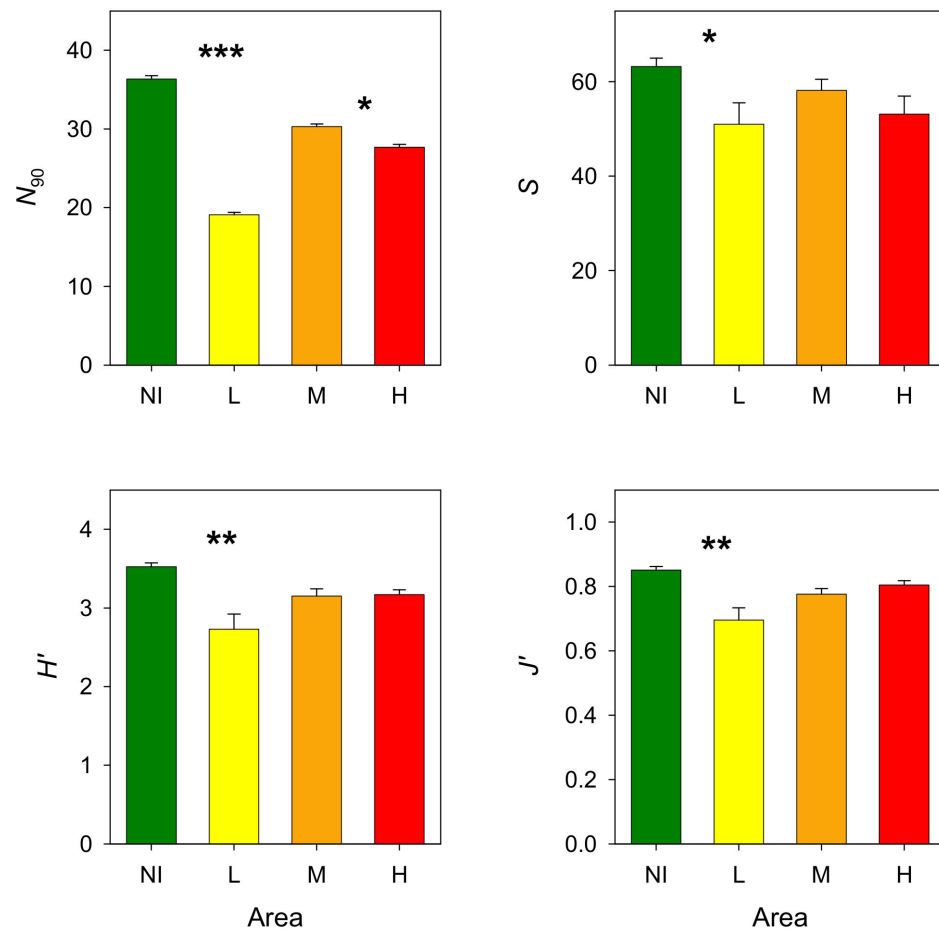


Figure 6. Mean values and standard errors of N_{90} , Species Richness (S), Shannon (H'), and Pielou's evenness (J') diversity indices, estimated from beam trawl samples in the four areas considered: Non-impacted (NI), Low effort history (L), Medium effort history (M), and High effort (H). p -values of the Student's t -test to test for differences between areas are presented: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

In the central part of the Menorca Channel, SIMPER table showed that main species contributing to similarity in the Non-impacted area were the crustaceans *Inachus dorsettensis*, *Pagurus prideaux*, and *Anapagurus laevis*, the fish *Buenia massutti*, and the ascidian *Ascidia mentula* (Table 2). In Low effort history area, these species were the same, with the only exception of the echinoderm *Ophiura ophiura* instead of *A. mentula*. This species, jointly with the other ascidian *Aplidium nordmanni* and the echinoderm *Echinaster sepositus* showed higher abundances in Non-impacted compared to Low effort history area. The sponges *Mycale (Aegogropila) contarenni*, *Calcarea* sp. and *Siphonochalina* sp., as well as the ascidians *Diazona violacea* and *Polycarpa mamillaris*, just contribute to similarity in Non-impacted area.

Table 2. Results of SIMPER analysis, estimated from standardized abundance data in beam trawl samples in Non-impacted and Low effort history areas, showing mean abundance (A; individuals/1000 m²) and percentage contribution (%C) of each species contributing up to 90% of within-group similarity.

Species/Taxa	Non-Impacted		Species/Taxa	Low Effort History	
	A	%C		A	%C
<i>Inachus dorsettensis</i>	113.1	12.3	<i>Pagurus prideaux</i>	267.0	35.4
<i>Buenia massutii</i>	99.2	11.2	<i>Buenia massutii</i>	118.3	12.8
<i>Pagurus prideaux</i>	74.9	7.4	<i>Inachus dorsettensis</i>	67.3	10.7
<i>Ascidia mentula</i>	64.7	6.7	<i>Anapagurus laevis</i>	39.3	3.9
<i>Anapagurus laevis</i>	73.2	5.3	<i>Ophiura ophiura</i>	27.0	3.7
<i>Liocarcinus</i> spp.	45.8	4.2	<i>Pagurus forbesii</i>	19.4	2.8
<i>Aplidium nordmanni</i>	57.1	4.2	<i>Ascidia mentula</i>	14.9	2.3
<i>Ophiura albida</i>	48.8	4.0	<i>Aplidium nordmanni</i>	25.6	2.0
<i>Ciona</i> spp.	28.0	2.6	<i>Dardanus arrosor</i>	16.3	1.9
<i>Pilumnus spinifer</i>	19.0	2.2	<i>Spatangus purpureus</i>	84.5	1.9
<i>Spatangus purpureus</i>	46.5	2.2	<i>Molgula appendiculata</i>	21.9	1.9
<i>Dardanus arrosor</i>	18.1	2.0	<i>Eurynome aspera</i>	15.1	1.9
<i>Pagurus forbesii</i>	18.8	2.0	<i>Calyptrea chinensis</i>	16.3	1.8
<i>Palliolium</i> spp.	18.3	1.9	<i>Fusinus pulchellus</i>	13.9	1.6
<i>Mimachlamys varia</i>	26.0	1.7	<i>Turritella turbona</i>	10.2	1.4
<i>Mycale (Aegogropila) contarenni</i>	16.2	1.7	<i>Pilumnus spinifer</i>	10.5	1.2
<i>Turritella turbona</i>	20.9	1.3	<i>Cystodytes dellechiaiei</i>	12.0	1.1
<i>Macropodia linaresi</i>	14.4	1.2	<i>Ophiura albida</i>	8.7	1.1
<i>Ebalia tuberosa</i>	12.8	1.1	<i>Echinaster sepositus</i>	5.7	0.8
<i>Eurynome aspera</i>	18.0	1.1			
<i>Parthenopoides massena</i>	20.1	1.1			
<i>Inachus thoracicus</i>	10.4	1.0			
<i>Molgula appendiculata</i>	10.1	1.0			
<i>Ophiura ophiura</i>	19.5	1.0			
<i>Pisa armata</i>	9.0	1.0			
<i>Polycarpa mamillaris</i>	10.9	0.9			
<i>Calcarea</i> sp.	15.6	0.8			
<i>Macropodia rostrata</i>	7.7	0.8			
<i>Laevicardium oblongum</i>	8.1	0.8			
<i>Cystodytes dellechiaiei</i>	11.7	0.8			
<i>Arnoglossus thori</i>	6.8	0.8			
<i>Vanneaugobius dollfusi</i>	18.2	0.7			
<i>Calyptrea chinensis</i>	9.2	0.7			
<i>Diazona violacea</i>	6.5	0.7			
<i>Clausinella fasciata</i>	6.7	0.7			
<i>Siphonochalina</i> sp.	10.7	0.7			
<i>Echinaster sepositus</i>	9.8	0.6			

In the southern part of the Menorca Channel, species that most contribute to similarity in Medium effort history area were the echinoderms *Ophioconis forbesi* and *Spatangus purpureus*, the crustaceans *P. prideaux* and *A. laevis*, and the ascidian *A. nordmanni*; while these same species, except *S. purpureus*, jointly with the crustacean *Pagurus forbesii* and the gastropod mollusk *Gibbula fanulum*, were the important species contributing to similarity in High effort area (Table 3). Species such as *S. purpureus*, *P. prideaux*, *E. sepositus*, *Dardanus arrosor*, *I. dorsettensis*, *Inachus thoracicus*, and *A. mentula* showed higher abundances in Medium effort history area compared to High effort area. The sponge *Suberites domuncula* and the ascidian *P. mamillaris* just contribute to similarity in Medium effort history area.

Table 3. Results of SIMPER analysis, estimated from standardized abundance data in beam trawl samples in Medium effort history and High effort areas, showing mean abundance (A; individuals/1000 m²) and percentage contribution (%C) of each species contributing up to 90% of within-group similarity.

Species/Taxa	Medium Effort History		Species/Taxa	High Effort	
	A	%C		A	%C
<i>Ophioconis forbesi</i>	307.1	16.3	<i>Ophioconis forbesi</i>	250.8	23.4
<i>Pagurus prideaux</i>	138.4	11.7	<i>Anapagurus laevis</i>	88.2	10.3
<i>Anapagurus laevis</i>	106.5	6.8	<i>Pagurus prideaux</i>	99.4	8.7
<i>Aplidium nordmanni</i>	121.6	6.6	<i>Pagurus forbesii</i>	48.1	6.4
<i>Spatangus purpureus</i>	114.8	5.2	<i>Gibbula fanulum</i>	47.1	4.4
<i>Molgula appendiculata</i>	111.1	4.3	<i>Dardanus arrosor</i>	41.4	3.7
<i>Dardanus arrosor</i>	49.5	3.8	<i>Turritella turbona</i>	29.9	2.7
<i>Cestopagurus timidus</i>	39.4	3.4	<i>Echinaster sepositus</i>	26.4	2.6
<i>Pagurus forbesii</i>	37.8	3.2	<i>Molgula appendiculata</i>	32.7	2.5
<i>Turritella turbona</i>	48.0	2.9	<i>Paguristes eremita</i>	31.2	2.4
<i>Echinaster sepositus</i>	33.0	2.4	<i>Cestopagurus timidus</i>	30.2	2.1
<i>Calyptrea chinensis</i>	36.0	2.2	<i>Ophiopsila aranea</i>	55.5	2.0
<i>Inachus dorsettensis</i>	32.3	2.1	<i>Ebalia tuberosa</i>	21.9	1.9
<i>Ebalia tuberosa</i>	23.5	2.1	<i>Buenia affinis</i>	28.3	1.7
<i>Gibbula fanulum</i>	28.8	2.0	<i>Clausinella fasciata</i>	13.4	1.7
<i>Liocarcinus</i> spp.	29.9	1.9	<i>Calyptrea chinensis</i>	18.1	1.7
<i>Buenia affinis</i>	71.7	1.6	<i>Aplidium nordmanni</i>	29.3	1.6
<i>Ophiopsila aranea</i>	76.0	1.5	<i>Inachus dorsettensis</i>	15.9	1.3
<i>Galathea intermedia</i>	22.8	1.1	<i>Ophiura albida</i>	15.1	1.2
<i>Inachus thoracicus</i>	15.0	1.0	<i>Parthenopoides massena</i>	16.4	1.1
<i>Suberites domuncula</i>	13.8	0.9	<i>Buenia massutii</i>	24.9	1.1
<i>Buenia massutii</i>	20.9	0.9	<i>Serranus hepatus</i>	35.7	1.0
<i>Ascidia mentula</i>	11.1	0.9	<i>Lanice conchilega</i>	8.9	1.0
<i>Polycarpa mamillaris</i>	14.5	0.8	<i>Diplecogaster bimaculata bimaculata</i>	9.4	0.9
<i>Mimachlamys varia</i>	20.3	0.7	<i>Ascidia mentula</i>	7.9	0.8
<i>Serranus hepatus</i>	26.5	0.7	<i>Laetmonice hystrix</i>	12.5	0.7
<i>Parthenopoides massena</i>	10.2	0.7	<i>Pagurus cuanensis</i>	7.1	0.7
<i>Paguristes eremita</i>	12.4	0.7	<i>Inachus thoracicus</i>	10.2	0.7
<i>Macropodia rostrata</i>	9.1	0.7			
<i>Odondebuena balearica</i>	10.6	0.7			
<i>Eurynome aspera</i>	10.0	0.6			

3.3. Rhodoliths

Differences in rhodoliths composition were observed by comparing Non-impacted and Low effort history areas with respect to Medium effort history and High effort areas (Figure 7). In the central part of the Menorca Channel, biomass of *L. valens* and *S. fruticosus* was higher in Non-impacted area (45.0 ± 15.2 and 33.2 ± 13.2 kg/1000 m², respectively) than in Low effort history area (4.1 ± 0.8 and 11.7 ± 4.32 kg/1000 m², respectively). No significant differences in biomass of *Phymatolithon calcareum* were found between Non-impacted and Low effort history areas (4 ± 3 and 3 ± 1 kg/1000 m², respectively).

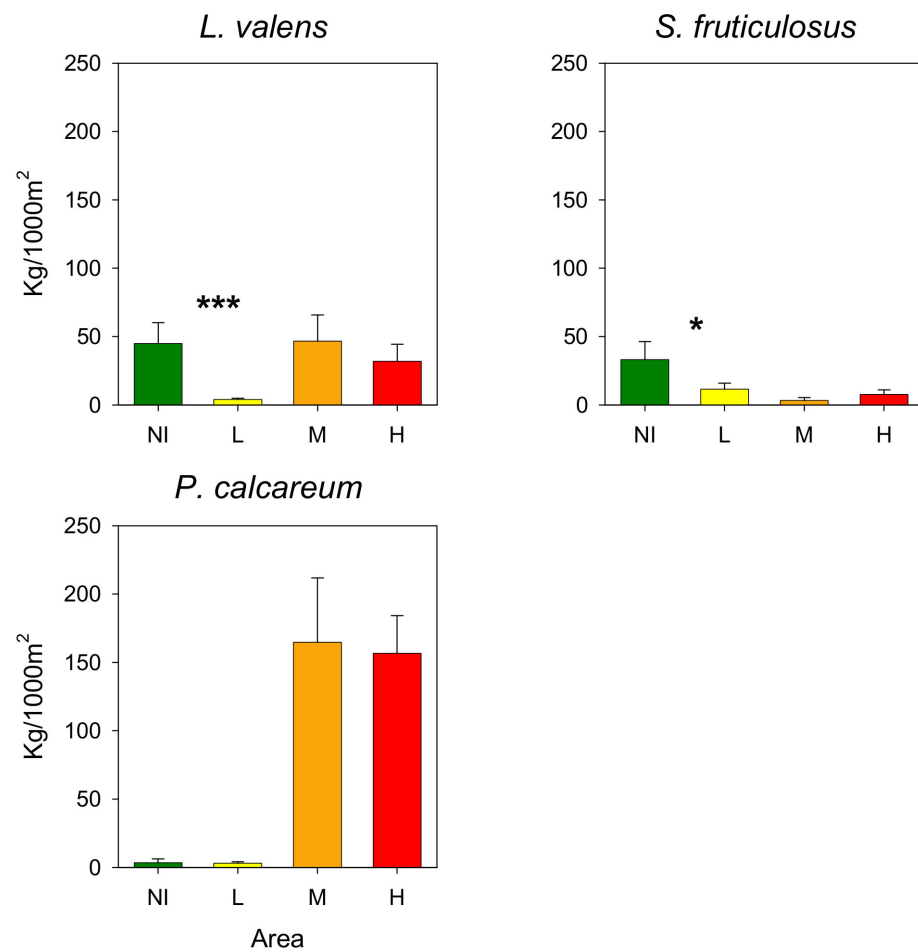


Figure 7. Mean values and standard errors of biomass (kg/1000 m²) for the three species of rhodoliths, estimated from beam trawl samples in the four areas considered: Non-impacted (NI), Low effort history (L), Medium effort history (M), and High effort (H). *p*-values of the Student's *t*-test to test for differences between areas are presented. * *p* < 0.05; ** *p* < 0.01; *** *p* < 0.001.

Mean values of size and roundness for the rhodolith species selected are shown in Figure 8. Size and roundness of *L. valens* were higher in Non-impacted area (size: 44.5 ± 1 mm; roundness: 0.43 ± 0.01) than in Low effort history area (size: 40.8 ± 0.9 mm; roundness: 0.37 ± 0.01). Size and roundness of *S. fruticulosus* were also higher in Non-impacted area (size: 35.8 ± 0.7 mm; roundness: 0.73 ± 0.01) than in Low effort history area (size: 32.4 ± 0.7 mm; roundness: 0.67 ± 0.01). *P. calcareum* did not show significant differences in size in any area, but it showed higher values of roundness in Non-impacted area (0.30 ± 0.02) compared to Low effort history area (0.25 ± 0.01).

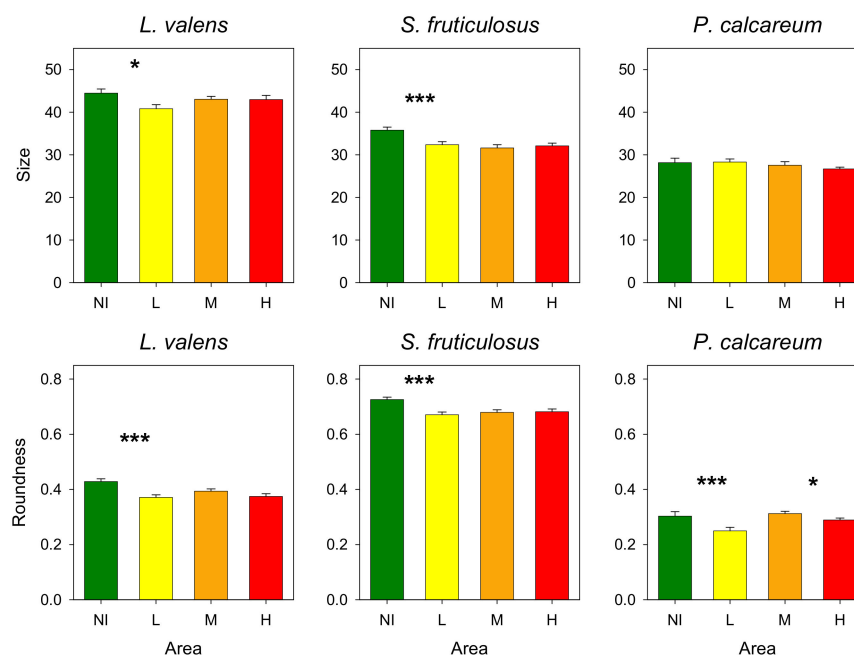


Figure 8. Mean values and standard errors of size (mm) and roundness for the three species of rhodoliths, estimated from beam trawl samples in the four areas considered: Non-impacted (NI), Low effort history (L), Medium effort history (M), and High effort (H). *p*-values of the Student's *t*-test to test for differences between areas are presented. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

In the southern part of the Menorca Channel, no significant differences in biomass of the considered species were found between Medium effort history and High effort area (Figure 7). *P. calcareum* showed higher values of roundness in Medium effort history (0.31 ± 0.01) compared to High effort area (0.29 ± 0.01 ; Figure 8).

Coverage of rhodoliths was higher in Non-impacted compared to Low effort history area (16.3 ± 2.0 and $9.2 \pm 1.2\%$, respectively) and in Medium effort history compared to High effort area (52.2 ± 5.3 and $36.2 \pm 2.2\%$, respectively; Figure 9).

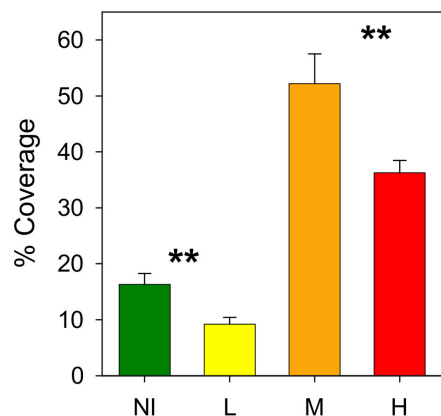


Figure 9. Mean values and standard errors of rhodoliths percentage coverage, estimated from visual transects with the TASIFE photogrammetric sledge in the four areas considered: Non-impacted (NI), Low effort history (L), Medium effort history (M), and High effort (H). *p*-values of the Student's *t*-test to test for differences between areas are presented. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

3.4. Bottom Trawl Captures

Benthic species captured by the bottom trawl fleet in the study area are presented in Table 4. In the Low effort history area, the most important species or taxa in the catches were the echinoderms *O. ophiura* and *E. sepositus*, the ascidian *A. mentula*, and the crustaceans *D. arrosor*, as well as other hermit crabs that could not be identified on board.

Table 4. Average values of abundance, in terms of individuals (n) per 30 min of fishing, of the main epibenthic species caught in commercial hauls, estimated from the sampling of scientific observers on board the trawling fleet in the Low effort history area, as well as in the Medium effort history and High effort areas, considered in the present study.

Low Effort History	$n/30'$	se
<i>Ophiura ophiura</i>	5.7	2.9
<i>Paguridae</i>	5.2	4.6
<i>Echinaster sepositus</i>	2.8	1.4
<i>Ascidia mentula</i>	2.3	1.1
<i>Dardanus arrosor</i>	2.3	1.6
<i>Pagurus prideauxi</i>	1.7	1.7
<i>Parastichopus regalis</i>	1.3	0.6
<i>Aplidium</i> spp.	1.0	0.5
<i>Suberites domuncula</i>	0.7	0.3
<i>Aequipecten opercularis</i>	0.7	0.4
<i>Molgula appendiculata</i>	0.7	0.7
<i>Inachus thoracicus</i>	0.7	0.4
<i>Marthasterias glacialis</i>	0.5	0.3
<i>Phallusia mammillata</i>	0.5	0.5
<i>Pleurobranchia meckeli</i>	0.5	0.5
<i>Botryllus schlosseri</i>	0.5	0.5
Medium effort history and High effort	$n/30'$	se
<i>Dardanus arrosor</i>	14.8	2.7
<i>Spatangus purpureus</i>	9.9	3.1
<i>Sphaerechinus granularis</i>	8.3	4.3
<i>Suberites domuncula</i>	8.3	2.3
<i>Pagurus prideaux</i>	5.7	4.8
<i>Echinaster sepositus</i>	2.8	0.6
<i>Ascidia mentula</i>	2.4	1.1
<i>Paguridae</i>	1.9	0.8
<i>Inachus</i> spp.	1.5	0.9
<i>Ascidia virginia</i>	1.0	0.7
<i>Aequipecten opercularis</i>	0.9	0.4
<i>Phallusia mammillata</i>	0.8	0.4
<i>Polycarpa mamillaris</i>	0.8	0.5
<i>Ophiura ophiura</i>	0.7	0.3
<i>Parastichopus regalis</i>	0.6	0.4
<i>Diazona violacea</i>	0.5	0.3
<i>Aplidium</i> spp.	0.5	0.2
<i>Ophiura</i> spp.	0.5	0.3
<i>Luidia ciliaris</i>	0.5	0.4

In the southern part of the Menorca Channel, the most abundant epibenthic species captured were also the hermit crabs *D. arrosor* and *P. prideaux*, the echinoderms *S. purpureus* and *Sphaerechinus granularis*, and the sponge *S. domuncula*.

4. Discussion

The present study has compared the conservation state of rhodoliths beds in four areas of the Site of Community Importance Menorca Channel, subjected to different levels of bottom trawl fishing effort. The results have shown clear differences in the composition and diversity of epibenthic communities, as well as in the size and morphology of the rhodolith species analyzed, due to the impact of bottom trawl fishing activity.

Areas located in the central part of the Menorca Channel (Non-impacted and Low effort history) showed differences in seafloor bathymetry, sediment type, and velocity of bottom currents compared to areas located in the southern part (Medium effort history and High effort). Light is considered one of the most important environmental factors influencing the distribution of benthic organisms on the continental shelf [29,51,52], to-

gether with sediment type [53–60]. In fact, the decreases in light irradiance and bottom currents velocities with depth have been argued as factors explaining the morphology and distribution of rhodolith species [20,22,61]. Burial and reduction of live rhodoliths increase in substrates with a high proportion of fine sediment [62,63]. On the other hand, the effects of bottom trawling on epibenthic communities lead to changes in community structure and biodiversity [20,64–67], also changing the composition and morphology of rhodoliths beds [20–22]. The comparison of all the areas between them could mask the effect of bottom trawling, due to the strong variability that causes the environmental conditions on the epibenthic communities analyzed. In order to block it, we compared similar environmental scenarios: (i) Non-impacted was compared to its adjacent Low effort history area; and (ii) Medium effort history was compared to its adjacent High effort area. The higher similarity among samples within Medium effort history and High effort areas than among the Non-impacted and Low effort history areas also points to a homogenization effect of bottom trawling on epibenthic communities.

The impact of fishing activities on rhodoliths and coralligenous beds in the Menorca Channel was assessed in the study developed by Moranta et al. [38]. Their results were not conclusive in relation to the intensity effect of bottom trawling on rhodoliths beds, so changes in size and morphology of rhodoliths in the area were better explained by current velocity, depth, and rhodoliths coverage. However, the results also suggest that the reduction of the complexity of size and morphologic structure of rhodoliths could be related with the incipient effects of fishing intensity in the area, where its impact was not detected by changes in algal biomass and megafaunal species composition [68].

On the contrary, thanks to the block of environmental conditions and the comparison of areas with different bottom trawling pressure, the results obtained in the present study have shown clear effects of bottom trawling on the composition and diversity of epibenthic communities of Non-impacted compared to Low effort history areas and some recovery signals by comparing Medium effort history and High effort areas. The decrease in abundances of sponges and ascidians, a structured habitat species on sedimentary bottoms, in higher impacted areas could be related to the sensitivity of those species [69,70] and its higher capturability by bottom trawling activity. The wide presence of megabenthic species in the Menorca channel makes them a good proxy to determine the effects of fishing activities. In fact, species such as *Ascidia mentula*, *Aplidium nordmanni*, and *Suberites domuncula* are important by-catch species of the trawling fleet in the Menorca Channel and in the whole Balearic Islands [21,24]. The presence of those species in lower impacted areas may indicate that epibenthic communities have started to recover from the effects of bottom trawling. The same occurs with *Spatangus purpureus*, an echinoderm species that is also an important capture of the commercial fleet in the southern part of the Menorca Channel, which showed higher abundances in the Medium effort history compared to the High effort area.

Another proxy to determine the effect of any impact is to evaluate the variability in size and morphology of fragile species. Ramified rhodoliths are good indicators to detect the effect of the physical impact, and changes in size and roundness in ramified (*Lithothamnion valens* and *Phymatolithon calcareum*) and nucleated (*Spongites fruticosus*) species have been found in previous works [22]. However, the low growing rates of rhodolith species [71] could be the cause that the three species considered had not yet recovered after three years of bottom trawling exclusion in the Medium effort history area. Contrary to the expected results, biomass and size of *P. calcareum* do not seem to be affected by bottom trawling, whereas higher roundness values were found in Non-impacted and Medium effort history areas, compared to Low effort history and High effort areas, respectively. The explanation focuses on the smallest size of *P. calcareum*, with a mean size lower than 30 mm in the four areas, and this could make it less sensitive to the pass of the bottom trawl net, suffering just changes in roundness. In fact, the nets used by the trawling fleet on the continental shelf of the Balearic Islands have a 40 mm square mesh, and they are traditionally adapted to reduce by-catch of non-commercial benthic species to improve the quality of landings. The comparison of mean density of rhodoliths, estimated from

beam trawl samples (130,000 kg/km² in the central part of the Menorca Channel and 309,649 kg/km² in the southern part) and commercial hauls (12 kg/km² in the central part of the Menorca Channel and 52 kg/km² in the southern part) of the trawling fleet, confirms that these nets avoid rhodolith captures. The decrease in frictions between rhodoliths and commercial species by means of the reduction of the capture of rhodoliths is a relevant measure to improve the quality of landings.

However, the results indicate that the time between the implementation in 2016 of the Fishing Protected Zones in a great part of the continental shelf of the Menorca Channel, where trawling fleet was excluded, and the sampling period (2019) has not been enough to recover their epibenthic communities. Otherwise, we would not have been able to detect differences between Non-impacted and Low effort history areas in the central part of the Menorca Channel, and we would have detected more differences between Medium effort history and High effort areas in the southern part. Besides, benthic-forming species show very low annual taxes of growing, both for calcareous or non-calcareous species [72], even if the environmental conditions are optimal, such as in the Menorca Channel [52]. In addition to the sensitivity of species [73], recovery of epibenthic communities depends on the time that has passed since the bottom trawling had impacted areas and the intensity of bottom trawling [74,75]. As a consequence, epibenthic communities of the Menorca Channel can show successional stages of recovery, but they have still not completely returned to the state they were in without bottom trawling.

The results contribute new scientific information about the impact of fishing activities on rhodoliths beds, needed for the development of the management plan required for the designation of the Menorca Channel as a Special Area of Conservation. The creation of the Fishing Protected Zones in 2016 has shown to be an effective measure to recover the epibenthic communities of the Menorca Channel. Additional technical measures on fishing gear to reduce the impact of bottom trawling, such as the modification of the ground rope of nets and the use of semi-pelagic doors, for which the efficiencies have been already tested in the area [24,76], should be considered to be implemented in areas opened to this fishery.

For the development of this management plan, studies on the impact of small-scale fisheries on the benthic communities of the Menorca Channel will also be necessary. Especially regarding the coralligenous beds, which are widely distributed in the area [36,77], and the use of trammel nets to exploit the European spiny lobster (*Palinurus elephas*), taking into account that this is one of the most important demersal fisheries developed by the small scale fleet, and that the most important fishing grounds are located in the Menorca Channel [38,78]. In this sense, preliminary results about the effects of trammel nets on coralligenous beds, developed in the ECOSAFIMED framework project, suggest lower percentages of biogenic substrates and richness of megabenthic species in fishing grounds subjected to greater fishing pressure. This effect could be mitigated with measures such as returning the sessile benthic by-catch at the same site where it has been captured and returning all the benthic by-catch to the sea in less than 30 min.

The Menorca Channel is one of the main areas of rhodoliths beds in the western Mediterranean. The negative impacts of bottom trawling on these beds and the first signals of their recovery in areas recently closed to this fishery, as shown in the results obtained in the present study, indicate that this is an effective measure for the conservation of this habitat of special interest and must be included in the management plan required to declare the Menorca Channel as a Special Area of Conservation.

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References

- Basso, D.; Babbini, L.; Kaleb, S.; Bracchi, V.; Falace, A. Monitoring deep Mediterranean rhodoliths beds. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2015**, *26*, 549–561. [\[CrossRef\]](#)
- Foster, M.S. Rhodoliths: Between rocks and soft places. *J. Phycol.* **2001**, *37*, 659–667. [\[CrossRef\]](#)
- Basso, D.; Babbini, L.; Ramos-Espla, A.A.; Salomidi, M. Mediterranean Rhodolith Beds. In *Rhodolith/Maërl Beds: A Global Perspective*; Riosmena-Rodríguez, R., Nelson, W., Aguirre, J., Eds.; Springer: Cham, Switzerland, 2017; pp. 282–298.
- Littler, M.M.; Littler, D.S.; Dennis Hanisak, M. Deep-water rhodolith distribution, productivity, and growth history at sites of formation and subsequent degradation. *J. Exp. Mar. Biol. Ecol.* **1991**, *150*, 163–182. [\[CrossRef\]](#)
- Wilson, S.; Blake, C.; Berges, J.A.; Maggs, C.A. Environmental tolerances of free-living coralline algae (maerl): Implications for European marine conservation. *Biol. Conserv.* **2004**, *120*, 279–289. [\[CrossRef\]](#)
- Steller, D.L.; Hernández-Ayón, J.M.; Riosmena-Rodríguez, R.; Cabello-Pasini, A. Efecto de la temperatura sobre las tasas de fotosíntesis, crecimiento y calcificación del alga coralina de vida libre *Lithophyllum margaritae*. *Ciencias Marinas* **2007**, *33*, 441–456. (In Spanish) [\[CrossRef\]](#)
- Steller, D.L.; Foster, M.S. Environmental factors influencing distribution and morphology of rhodoliths in Bahía Concepción, B.C.S., México. *J. Exp. Mar. Biol. Ecol.* **1995**, *194*, 201–212. [\[CrossRef\]](#)
- Hall-Spencer, J.M.; Moore, P.G. Scallop dredging has profound, long-term impacts on maerl habitats. *ICES J. Mar. Sci.* **2000**, *57*, 1407–1415. [\[CrossRef\]](#)
- Sciberras, M.; Rizzo, M.; Mifsud, J.R.; Camilleri, K.; Borg, J.A.; Lanfranco, E.; Schembri, P.J. Habitat structure and biological characteristics of a maerl bed off the Habitat structure and biological characteristics of a maerl bed off the northeastern coast of the Maltese Islands (central Mediterranean). *Mar. Biodiver.* **2009**, *39*, 251–264. [\[CrossRef\]](#)
- Barbera, C.; Bordehore, C.; Borg, J.A.; Glémarec, M.; Grall, J.; Hall-Spencer, J.M.; de la Huz, C.; Lanfranco, E.; Lastra, M.; Moore, P.G.; et al. Conservation and management of northeast Atlantic and Mediterranean maerl beds. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2003**, *13*, S65–S76. [\[CrossRef\]](#)
- Nelson, W.A. Calcified macroalgae: Critical to coastal ecosystems and vulnerable to change. *Mar. Freshw. Res.* **2009**, *60*, 787–801. [\[CrossRef\]](#)
- Teichert, S. Hollow rhodoliths increase Svalbard' shelf biodiversity. *Sci. Rep.* **2014**, *4*, 6972. [\[CrossRef\]](#)
- Keegan, B. The macrofauna of maerl substrates on the west coast of Ireland. *Cah. Biol. Mar.* **1974**, *15*, 513–530.
- Kamenos, N.A.; Moore, P.G.; Hall-Spencer, J.M. Small-scale distribution of juvenile gadoids in shallow inshore waters; what role does maerl play? *ICES J. Mar. Sci.* **2004**, *61*, 422–429. [\[CrossRef\]](#)
- Kamenos, N.A.; Moore, P.G.; Hall-Spencer, J.M. Nursery-area function of maerl grounds for juvenile queen scallops *Aequipecten opercularis* and other invertebrates. *Mar. Ecol. Prog. Ser.* **2004**, *274*, 183–189. [\[CrossRef\]](#)
- Peña, V.; Bárbara, I.; Grall, J.; Maggs, C.A.; Hall-Spencer, J.M. The diversity of seaweeds on maerl in the NE Atlantic. *Mar. Biodivers.* **2014**, *44*, 533–551. [\[CrossRef\]](#)
- Amado-Filho, G.M.; Moura, R.L.; Bastos, A.C.; Salgado, L.T.; Sumida, P.Y.; Guth, A.Z.; Francini-Filho, R.B.; Pereira-Filho, G.H.; Abrantes, D.P.; Brasileiro, P.S.; et al. Rhodolith beds are major CaCO₃ bio-factories in the tropical South West Atlantic. *PLoS ONE* **2012**, *7*, e35171. [\[CrossRef\]](#)
- Harvey, A.S.; Harvey, R.M.; Merton, E. The distribution, significance and vulnerability of Australian rhodolith beds: A review. *Mar. Freshw. Res.* **2016**, *68*, 411–428. [\[CrossRef\]](#)
- Sanz-Lázaro, C.; Belando, M.D.; Marín-Guirao, L.; Navarrete-Mier, F.; Marín, A. Relationship between sedimentation rates and benthic impact on Maerl beds derived from fish farming in the Mediterranean. *Mar. Environ. Res.* **2011**, *71*, 22–30. [\[CrossRef\]](#)
- Barberá, C.; Mallol, S.; Vergés, A.; Cabanellas-Reboredo, M.; Díaz, D.; Goñi, R. Maerl beds inside and outside a 25-year-old no-take area. *Mar. Ecol. Prog. Ser.* **2017**, *572*, 77–90. [\[CrossRef\]](#)
- Ordines, F.; Ramón, M.; Rivera, J.; Rodríguez-Prieto, C.; Farriols, M.T.; Guijarro, B.; Pasqual, C.; Massutí, E. Why long term trawled red algae beds off Balearic Islands (western Mediterranean) still persist? *Reg. Stud. Mar. Sci.* **2017**, *15*, 39–49. [\[CrossRef\]](#)

22. Cabanellas-Reboredo, M.; Mallol, S.; Barberá, C.; Vergés, A.; Díaz, D.; Goñi, R. Morpho-demographic traits of two maerl-forming algae in beds with different depths and fishing histories. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2017**, *28*, 133–145. [[CrossRef](#)]
23. Carbonell, A.; Martín, P.; De Ranieri, S.; WEDIS team. Discards of the western Mediterranean trawl fleets. *Rapp. Comm. Int. Pour l'Explor. Sci. Mer Méditerranée* **1998**, *35*, 392–393.
24. Farriols, M.T.; Ordines, F.; Massutí, E. Discards reduction of non-commercial benthic species from a simple net modification. *Fish. Res.* **2021**, *241*, 105985. [[CrossRef](#)]
25. Bordehore, C.; Ramos-Esplá, A.A.; Riosmena-Rodríguez, R. Comparative study of two maerl beds with different otter trawling history, southeast Iberian Peninsula. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2003**, *13*, S43–S54. [[CrossRef](#)]
26. Grall, J.; Hall-Spencer, J.M. Problems facing maerl conservation in Brittany. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2003**, *13*, 55–64. [[CrossRef](#)]
27. Ballesteros, E. Els fons rocosos profunds amb *Osmundaria volubilis* (Linné) R.E. Norris a les Balears. *Boll. Soc. Hist. Natur. Illes Balears* **1992**, *35*, 33–50.
28. Ballesteros, E. The deep-water Peyssonnelia beds from the Balearic Islands (western Mediterranean). *Mar. Ecol.* **1994**, *15*, 233–253. [[CrossRef](#)]
29. Ordines, F.; Massutí, E. Relationships between macro-epibenthic communities and fish on the shelf grounds of the western Mediterranean. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2009**, *19*, 370–383. [[CrossRef](#)]
30. Farriols, M.T.; Ordines, F.; Somerfield, P.J.; Pasqual, C.; Hidalgo, M.; Guijarro, B.; Massutí, E. Bottom trawl impacts on Mediterranean demersal fish diversity: Not so obvious or are we too late? *Cont. Shelf Res.* **2017**, *137*, 84–102. [[CrossRef](#)]
31. Acosta, A.; Canals, M.; López-Martínez, J.; Muñoz, A.; Herranz, P.; Urgeles, R.; Palomo, C.; Casamor, J.L. The Balearic Promontory geomorphology (western Mediterranean): Morphostructure and active processes. *Geomorphology* **2002**, *49*, 177–204. [[CrossRef](#)]
32. Canals, M.; Ballesteros, E. Production of carbonate particles by phytobenthic communities on the Mallorca-Menorca shelf, northwestern Mediterranean Sea. *Deep-Sea Res. II* **1997**, *44*, 611–629. [[CrossRef](#)]
33. Alonso, B.; Guillén, J.; Canals, M.; Serra, J.; Acosta, J.; Herranz, P.; Sanz, J.L.; Calafat, A.; Catafau, E. Los sedimentos de la plataforma balear. *Acta Geol. Hisp.* **1988**, *23*, 185–196. (In Spanish)
34. Pinot, J.M.; Tintoré, J.; Gomis, D. Multivariate analysis of the surface circulation in the Balearic Sea. *Progr. Oceanogr.* **1995**, *36*, 343–376. [[CrossRef](#)]
35. Pinot, J.-M.; Lopez-Jurado, J.L.; Riera, M. The CANALES experiment (1996–1998). Interannual, seasonal, and mesoscale variability of the circulation in the Balearic Channels. *Progr. Oceanogr.* **2002**, *55*, 335–370. [[CrossRef](#)]
36. Barberá, C.; Moranta, J.; Ordines, F.; Ramón, M.; de Mesa, A.; Díaz-Valdés, M.; Grau, A.M.; Massutí, E. Biodiversity and habitat mapping of Menorca Channel (western Mediterranean): Implications for conservation. *Biodivers. Conserv.* **2012**, *21*, 701–728. [[CrossRef](#)]
37. Grinyó, J.; Gori, A.; Greenacre, M.; Requena, S.; Canepa, A.; Iacono, C.L.; Ambroso, S.; Purroy, A.; Gili, J.M. Megabenthic assemblages in the continental shelf edge and upper slope of the Menorca Channel, Western Mediterranean Sea. *Progr. Oceanogr.* **2018**, *162*, 40–51. [[CrossRef](#)]
38. Moranta, J.; Barberá, C.; Druet, M.; Zaragoza, N. *Caracterización Ecológica de La Plataforma Continental (50–100 m) del Canal de Menorca, Informe Final LIFE+ INDEMARES (LIFE07/NAT/E/000732)*; Instituto de Ciencias del Mar–CSIC: Barcelona, Spain, 2014. (In Spanish)
39. Folk, R.L. The distinction between grain size and mineral composition in sedimentary-rock nomenclature. *J. Geol.* **1954**, *62*, 344–359. [[CrossRef](#)]
40. Jennings, S.; Lancaster, J.; Woolmer, A.; Cotter, J. Distribution, diversity and abundance of epibenthic fauna in the North Sea. *J. Mar. Biol. Assoc.* **1999**, *79*, 385–399. [[CrossRef](#)]
41. Reiss, H.; Kröncke, I.; Ehrlich, S. Estimating the catching efficiency of a 2-m beam trawl for sampling epifauna by removal experiments. *ICES J. Mar. Sci.* **2006**, *63*, 1453–1464. [[CrossRef](#)]
42. Schneider, C.A.; Rasband, W.S.; Eliceiri, K.W. NIH image to ImageJ: 25 years of image analysis. *Nat. Methods* **2012**, *9*, 671–675. [[CrossRef](#)] [[PubMed](#)]
43. Shchepetkin, A.F.; McWilliams, J.C. The Regional Ocean Modeling System (ROMS): A split-explicit, free-surface, topography-following-coordinate oceanic model. *Ocean Model.* **2005**, *9*, 347–404. [[CrossRef](#)]
44. Juza, M.; Mourre, B.; Renault, L.; Gómara, S.; Sebastián, K.; Lora, S.; Beltran, J.P.; Frontera, B.; Garau, B.; Troupin, C.; et al. SOCIB operational ocean forecasting system and multi-platform validation in the Western Mediterranean Sea. *J. Oper. Oceanogr.* **2016**, *9*, s155–s166. [[CrossRef](#)]
45. Mourre, B.; Aguiar, E.; Juza, M.; Hernandez-Lasheras, J.; Reyes, E.; Heslop, E.; Escudier, R.; Cutolo, E.; Ruiz, S.; Mason, E.; et al. Assessment of high-resolution regional ocean prediction systems using multi-platform observations: Illustrations in the Western Mediterranean Sea. In *New Frontiers in Operational Oceanography*; Chassignet, E., Pascual, A., Tintoré, J., Verron, J., Eds.; GODAE Ocean View: Berlin, Germany, 2018; pp. 663–694.
46. Hernandez-Lasheras, J.; Mourre, B. Dense CTD survey versus glider fleet sampling: Comparing data assimilation performance in a regional ocean model West of Sardinia. *Ocean Sci.* **2018**, *14*, 1069–1084. [[CrossRef](#)]
47. Bray, J.R.; Curtis, J.T. An ordination of the upland forest communities of southern Wisconsin. *Ecol. Monogr.* **1957**, *27*, 325–349. [[CrossRef](#)]
48. Clarke, K.R. Non-parametric multivariate analyses of changes in community structure. *Aust. J. Ecol.* **1993**, *18*, 117–143. [[CrossRef](#)]

49. Farriols, M.T.; Ordines, F.; Massuti, E. N_{90} , a Diversity Index Sensitive to Variations in Beta Diversity Components. *Diversity* **2021**, *13*, 489. [\[CrossRef\]](#)
50. Clarke, K.R.; Gorley, R.N.; Somerfield, P.J.; Warwick, R.M. *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation*, 3rd ed.; PRIMER-E: Plymouth, UK, 2014; 260p.
51. Martí, R.; Uriz, M.J.; Ballesteros, E.; Turon, X. Seasonal variation in structure of three algal communities under different Light conditions. *Estuar. Coast. Shelf Sci.* **2005**, *64*, 613–622. [\[CrossRef\]](#)
52. Ballesteros, E. Mediterranean coralligenous assemblages: A synthesis of present knowledge. In *Oceanography and Marine Biology: An Annual Review*; Gibson, R.N., Atkinson, R.J.A., Gordon, J.D.M., Eds.; Taylor & Francis: Boca Raton, FL, USA, 2006; Volume 44, pp. 123–195.
53. Peterson, C.G.J. The animal communities of the sea bottom. *Rep. Dan. Biol. Stn.* **1913**, *21*, 1–44.
54. Thorson, G. Bottom communities (sublittoral or shallow shelf). *Geol. Soc. Am. Mem.* **1957**, *67*, 461–534.
55. Pérès, J.M.; Picard, J. Nouveau manuel de bionomie benthique de la mer Méditerranée. *Rec. Trav. Stat. Mar. Endoume.* **1964**, *31*, 1–137. (In French)
56. Glemarec, M. The benthic communities of the European North Atlantic continental shelf. *Oceanogr. Mar. Biol.* **1973**, *11*, 263–289.
57. Gray, J.S. Animal–sediment relationships. *Oceanogr. Mar. Biol.* **1974**, *12*, 223–261.
58. Buchanan, J.B.; Shearer, M.; Kingston, P.F. Sources of variability in the benthic environment off the south Northumber- land Coast, 1971–1976. *J. Mar. Biolog. Assoc.* **1978**, *58*, 191–209. [\[CrossRef\]](#)
59. Flint, R.W.; Holland, J.S. Benthic fauna variability on a transect in the Gulf of Mexico. *Estuar. Coast. Shelf Sci.* **1980**, *10*, 1–14. [\[CrossRef\]](#)
60. Pérès, J.M. History of the Mediterranean biota and the colonization of the depths. In *Western Mediterranean*; Margalef, R., Ed.; Pergamon Press: London, UK, 1985; pp. 200–234.
61. Otero-Ferrer, F.; Cosme, M.; Tuya, F.; Espino, F.; Haroun, R. Effect of depth and seasonality on the functioning of rhodolith seabeds. *Estuar. Coast. Shelf Sci.* **2020**, *235*, 106579. [\[CrossRef\]](#)
62. Steller, D.L.; Riosmena-Rodríguez, R.; Foster, M.S.; Roberts, C.A. Rhodolith bed diversity in the Gulf of California: The importance of rhodolith structure and consequences of disturbance. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2003**, *13*, S5–S20. [\[CrossRef\]](#)
63. Dutertre, M.; Grall, J.; Ehrhold, A.; Hamon, D. Environmental factors affecting maerl bed structure in Brittany (France). *Eur. J. Phycol.* **2015**, *50*, 371–383. [\[CrossRef\]](#)
64. Engel, J.; Kvitek, R. Effects of otter trawling on a benthic community in Monterey Bay National Marine Sanctuary. *Conserv. Biol.* **1998**, *12*, 1204–1214. [\[CrossRef\]](#)
65. Smith, C.J.; Papadopoulou, K.N.; Diliberto, S. Impact of otter trawling on an eastern Mediterranean commercial trawl fishing ground. *ICES J. Mar. Sci.* **2000**, *57*, 1340–1351. [\[CrossRef\]](#)
66. Hiddink, J.G.; Jennings, S.; Kaiser, M.J.; Queirós, A.M.; Duplisea, D.E.; Piet, G.J. Cumulative impacts of seabed trawl disturbance on benthic biomass, production, and species richness in different habitats. *Can. J. Fish. Aquat. Sci.* **2006**, *736*, 721–736. [\[CrossRef\]](#)
67. Hinz, H.; Prieto, V.; Kaiser, M.J. Trawl disturbance on benthic communities: Chronic effects and experimental predictions. *Ecol. Appl.* **2009**, *19*, 761–773. [\[CrossRef\]](#)
68. Barberá, C.; Comalada, N.; Joher, S.; Valls, M.; Díaz-Valdés, M.; Moranta, J. Analysis of morphological characteristics of rhodoliths as indicator of habitat complexity and fishing pressure. XVII Iberian Symposium on Marine Biology Studies. *Rev. Investigación Mar. AZTI-Tecnalia* **2012**, *19*, 346.
69. Arroyo, E.; Moya-Urbano, E.; García-Ruiz, C.; Esteban, A.; Ramos-Esplá, A.A. Ascidiens (Chordata: Tunicata) from circalittoral and upper-bathyal soft bottoms sampled by experimental trawling in the Iberian Mediterranean Sea. *Reg. Stu. Mar. Sci.* **2021**, *43*, 101669. [\[CrossRef\]](#)
70. Freese, J.L. Trawl-induced damage to sponges observed from a research submersible. *Mar. Fish. Rev.* **2003**, *63*, 7–13.
71. Birkett, D.A.; Maggs, C.A.; Dring, M.J. *Maerl (Volume 5). An Overview of Dynamic and Sensitivity Characteristics for Conservation Management of Marine SACs*; Scottish Association for Marine Science [UK Marine SACs Project]: Oban, UK, 1998; 116p.
72. Potin, P.; Floc’h, J.Y.; Augris, C.; Cabioch, J. Annual growth rate of the calcareous red alga *Lithothamnion corallioides* (Corallinales, Rhodophyta) in the Bay of Brest, France. *Hydrobiologia* **1990**, *204*, 263–267. [\[CrossRef\]](#)
73. Hiddink, J.G.; Jennings, S.; Kaiser, M.J. Assessing and predicting the relative ecological impacts of disturbance on habitats with different sensitivities. *J. Appl. Ecol.* **2007**, *44*, 405–413. [\[CrossRef\]](#)
74. Lambert, G.I.; Jennings, S.; Kaiser, M.J.; Davies, T.W.; Hiddink, J.G. Quantifying recovery rates and resilience of seabed habitats impacted by bottom fishing. *J. Appl. Ecol.* **2014**, *51*, 1326–1336. [\[CrossRef\]](#)
75. Kaiser, M.J. Significance of bottom-fishing disturbance. *Conserv. Biol.* **1998**, *12*, 1230–1235. [\[CrossRef\]](#)
76. Guijarro, B.; Ordines, F.; Massuti, E. Improving the ecological efficiency of the bottom trawl fishery in the Western Mediterranean: It’s about time! *Marine Policy* **2017**, *83*, 204–214. [\[CrossRef\]](#)
77. Grinyó, J.; Garriga, A.; Soler-Membrives, A.; Santín, A.; Ambroso, S.; López-González, P.J.; Díaz, D. Soft corals assemblages in deep environments of the Menorca Channel (Western Mediterranean Sea). *Progr. Oceanogr.* **2020**, *188*, 102435. [\[CrossRef\]](#)
78. Quetglas, A.; Merino, G.; Ordines, F.; Guijarro, B.; Garau, A.; Grau, A.M.; Oliver, P.; Massuti, E. Management Assessment and management of western Mediterranean small-scale fisheries. *Ocean Coast. Manag.* **2016**, *133*, 95–104. [\[CrossRef\]](#)