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Understanding the spatio-temporal variability of fisheries data for better bottom trawling management practices in the Catalan margin (NW Mediterranean Sea)

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ABSTRACT

The long-time fishery tradition on the Mediterranean coastal region without a biological-base management strategy has led to an overexploitation of the main fishing resources. To overturn this trend, the European Union implemented the Western Mediterranean Multi-Annual Plan (WMMAP) aiming to better manage key commercial species caught by bottom trawling. The data to drive management decisions should be obtained from fisheries monitoring programs designed to collect data that reflect dynamics of both biological and spatio-temporal trends in different spatial extents and scales. With this in mind, the aim of this research is to analyze the spatio-temporal variability of the commercial fraction of the catch, focusing on the main fishing resources of the Catalan bottom trawling fleet throughout the GSA 6. The Institut Català de Recerca per a la Governança del Mar (ICATMAR) designed a locally-based monitoring program to collect biological data for seven main key fishing resources of the area including the spottail mantis shrimp, the red mullet, the horned octopus, the European hake, the deep-water rose shrimp, the Norway lobster and the blue and red shrimp. The study shows the patterns that affect the main fishing resources exploited by the Catalan bottom trawling fleet over space and time through the study of biological data relevant to fisheries. To develop best management practices, we suggest that this type of sampling be included in Mediterranean areas to complement the current Data Collection Framework (DCF) program, so that fisheries can be managed evaluating the biology of the species along with the social component of the fisheries structure.

1. Introduction

In the Mediterranean Sea, maritime activities and the exploitation of marine living resources have remained relevant for thousands of years [1], and this long-time tradition has led to overfishing [2]. In response to this, in 2000 the European Union Data Collection Framework (DCF) established for member states the obligation to collect, manage and annually report biological, environmental and socioeconomic fisheries data as a source of scientific advice for management purposes (EU 2017/1004).

Fisheries data collection in the Mediterranean Sea is currently carried out through both fisheries-dependent and -independent information, collected by Geographical Subareas (GSAs), the management units defined by the General Fisheries Commission for the Mediterranean of the United Nations Food and Agriculture Organization (Resolution GFCM/33/2009/2). The geographical subareas are often used to define

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the size of the stock unit, meaning that the advice derived from stock assessment is referred to a particular GSA or a combination of GSAs. In practice, neither the distribution nor the status of a given stock are considered at a scale smaller than the GSA. In the GSA 6, the NE Spanish Mediterranean coast, bottom trawling fisheries-dependent data are gathered through the monitoring of commercial fisheries data on board and in auctions of some ports along the GSA 6, where the area is considered as a single unit. Bottom trawling fisheries-independent data are collected in annual surveys (MEDITS), in place since 1994 in late spring months, with an average of 85 yearly hauls along the whole GSA 6 [3,4]. Although these programs obtain accurate and reliable data on population structure and fishing stocks, the extension of the management unit is wide, encompassing an area with the highest number of fishers' associations and fishing vessels among all Mediterranean countries, so that aiming for an exhaustive sampling or year-round data collection along this whole area would not be feasible.

The design of a common management strategy for the EU is a complex matter, since fishing activity patterns and socio-economic contexts are diverse [5,6]. The management strategies at present in place are typically designed based on the North Atlantic fishery model, i.e., large vessels belonging to a few big companies, wide fishing areas trawled for weeks at a time, few fishery associations per region with non-daily auctions and large management units that suit a homogenous socio-economic structure. As a consequence, these strategies do not always translate well to the Spanish Mediterranean context, based on medium-small, family-owned vessels, with an average power of 180 kW, gross tonnage (GT) of 58, and length overall (LOA) of 20 m (versus 1257 kW, 1182 GT, and 60 m LOA for Spanish bottom trawl vessels fishing in the North Atlantic, respectively; EC Fleet Register 2024).

Another main characteristic of Mediterranean fisheries is the use of multiple gears and their markedly multi-specific nature, including a broad variety of target and discard species [7,8]. In fact, fisheries management in the Western Mediterranean Sea has traditionally followed a single-species approach (EU Reg. 2019/1022) [9,10], but some authors have argued that applying these single-management strategies to multi-specific fisheries may not be a good fit [11,12]. Finally, Mediterranean fishing activities also exhibit great variations from one area to another, from the point of view of production methods as well as the adaptation of human communities to the physical and biological environmental conditions [2].

Within the NW Mediterranean Sea, the Catalan coast comprises the northern half of the GSA 6, between the Spanish-French border and the Ebre Delta. Fisheries activities are deeply rooted in Catalan culture [13] and have historically been a main source of income and cultural identity for coastal communities. The three different modalities of commercial fishing practiced in the area are bottom trawling, purse seine fishing, and a large variety of small-scale fisheries. In 2022, the highest yearly revenues, around 55 million € (60 % of the total [14]), were reported by the bottom trawling fleet. The importance of bottom trawling spurred the development of a strong legislation that has already been in place for decades. The main management measures set by the 1960s pioneer collaborative management plan "Pla Castelló" – i.e. the widening of the mesh size up to 40 mm, and restrictions on number, fishing capacity and navigation time of vessels – are still enforced by the Spanish fishery regulation with a few updates after present EU regulations (EC 1626/1994; EC 1967/2006; Real Decreto 1440/1999). Along the Catalan coast, the collaboration among stakeholders has continued since, resulting in other self-regulated management initiatives [e.g. 14]. In this sense, each port may have its own implementation of fisheries regulations by internal agreements that go beyond European or member states management legislation. Actually, some of them host local co-management plans [15] focused on limiting fishing effort and enforcing biological monitoring of the target species and the communities (e.g., the blue and red shrimp in Palamós) [16]. These particularities call for a richer set of data that can inform decisions at a finer scale. The consideration of diverse types of data such as satellite-based information of fishing activities and of primary production, combined at a fine spatial scale, could improve the understanding of the ecosystems' response to environmental driving forces, and of the main trends of fishery indicators such as yield, productivity and overexploitation rate of fishing stocks [17].

In 2018 the EU regulation COM/2018/0115 final - 2018/050 (COD) implemented the Western Mediterranean Multi-Annual Plan (WMMAP), which establishes a progressive reduction in fishing effort (in days) for the bottom trawling fleet, in an effort to attain sustainable fishing securing economic, employment and social benefits based on the management of the following key commercial species: the red mullet, the European hake, the deep-water rose shrimp, the Norway lobster, and the blue and red shrimp. In Catalonia, and following the EU DCF, the Directorate-General for Maritime Policy and Sustainable Fisheries of the Catalan Government and the Institut de Ciències del Mar (ICM-CSIC) promoted the *Institut Català de Recerca per a la Governança del Mar* (ICATMAR), an autonomous organization whose main goal is to generate scientific advice to regional, state and European administrations for management purposes. Since 2019, ICATMAR has developed and implemented a fisheries monitoring program that aims to complement the data collection protocol already in place, working at a local scale to gather information on spatial and seasonal variability of the factors that can shape fishing stocks dynamics [4]. The program monitors the main target species of the Catalan commercial fleet but the present study focuses only on the bottom trawling fleet because of its key importance in landings and revenues of the northern GSA 6.

This study aims to analyze the spatio-temporal variability of the the main fishing resources of the Catalan bottom trawling fleet throughout the GSA 6. For this purpose, we analyzed biological data collected by a locally-based monitoring for seven key species of the area: the spottail mantis shrimp, the red mullet, the horned octopus, the European hake, the deep-water rose shrimp, the Norway lobster, and the blue and red shrimp. These data could potentially complement the official EU fisheries monitoring system dataset (DCF) to enrich the stock assessment models and improve accuracy in management decision-making processes.

2. Materials and methods

2.1. Study area

The study area comprises the entire Catalan coast, with 580 km of coastline, constitutes the northern half of the GSA 6, which in whole comprises from Cape Creus down to Cartagena (Resolution GFCM/33/2009/2). (Fig. 1A). The spatial distribution of the fishing effort by port shows the local-scale structure of the Catalan bottom trawling sector: the fleet of each port fishes in waters directly off their port, and overlapping among influence areas of the different ports is low (around 10 % in fishing hours per km^2, Mingote et al., in prep) and exists only among adjacent ports (Fig. 1A). We chose the 9 ports with the highest annual revenues which are also equidistant throughout the territory (Fig. 1A), attending to both hydrographic and geomorphological characteristics of the continental margin (shelf and slope) [18]. In the northernmost part of the Catalan coast, the continental shelf is cut by deep submarine canyons that allow for deep-sea fisheries activity while remaining relatively close to the coast. The coast between Arenys de Mar and Tarragona is characterized by the absence of submarine canyons and the influence of densely populated areas such as Barcelona, Vilanova i la Geltrú or Tarragona. The southernmost area of the coast is deeply affected by the discharge of the river Ebre, which generates a delta between L'Ampolla and La Ràpita. The division of the Catalan coast in these three zones responds to the morphometric mesoscale analysis of the margin [19] and has been used in previous faunistic assemblage studies [20]. Accordingly, the ports were classified in three sampling zones (north, center and south) as follows: Roses, Palamós, Blanes and Arenys de Mar in the northern zone; Barcelona, Vilanova i la Geltrú and

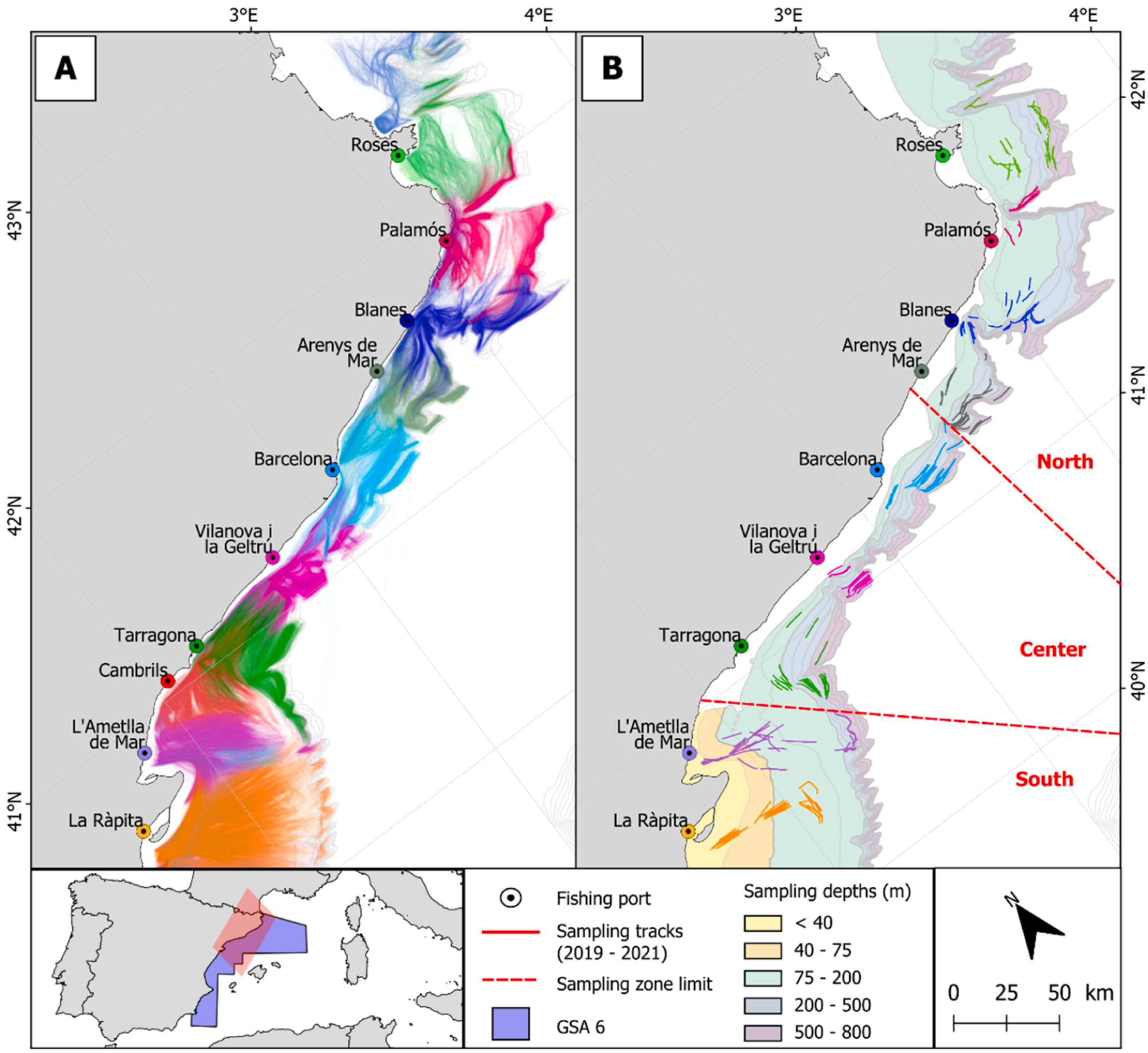

Fig. 1. Maps of the study area. The bottom image shows the GSA 6 (blue area), and the Catalan coast (red area). A: In color, fishing tracks (from Vessel Monitoring System, VMS data; for further information see [21]) of the Catalan bottom trawling fleet over the year 2021 represented by port. B: Sampling tracks followed in the ICATMAR monitoring in 2021, represented by zone (north, center, south), port and sampling depth range.

Tarragona in the central zone; and L'Ametlla de Mar and La Ràpita in the southern zone (Fig. 1B).

As described in the EU Reg. 1967/2006, the trawling fishing fleet from the Catalan coast is allowed to fish between 50 m depth (or 3 nautical miles from the coast) and 1000 m depth, five days per week (on weekdays) with a maximum of 12 hours per day (EC 1626/1994; EC 1967/2006). In shallow areas, such as the Ebre Delta (southernmost part of this study area; South Catalonia), trawling is allowed beyond 3 nautical miles off the coast, regardless of bottom depth.

The spatial distribution of the fishing effort shows high fishing activity in all depths where the bottom trawl fishery is allowed to fish by regulation. However, specific fishing effort varies according to the spatial distribution of the target species. Accordingly, different sampling depth ranges were defined along the Catalan coast. In the north and center zones, the sampling depth ranges defined are deep shelf (75 – 200 m), upper slope (200 – 500 m), and lower slope (500 – 800 m). In the southern area, which has a distinct geomorphological structure and bottom sedimentary characteristics, the defined sampling depths are coastal delta shelf (< 40 m), middle delta shelf (40 – 75 m), and deep shelf (75 – 200 m; Fig. 1). These depth strata are very similar to those applied by the MEDITS protocol, making the datasets potentially comparable [22].

2.2. Field sampling

Sampling trips were carried out on board trawling fishing vessels, with no change to their usual fishing activity, over commercial fishing grounds. Each of the three sampling zones was sampled monthly, with a rotation among the three ports of each zone, resulting in one quarterly sampling at each of the 9 selected ports. This allowed for the monitoring of seasonal patterns throughout the year. Each sampling day included three experimental hauls on board the same vessel, each one at one of the three depth ranges previously explained, within the high-fishing effort areas of each port (Supplementary Figure 2). Exceptionally, in 2019 and 2020, seven of the Southern zone hauls were conducted in the lower slope. The average depth for each haul was then estimated by calculating an average point between the start and end points of each haul. Mesh size was 40-mm square for all hauls except in Palamós lower slope, where the self-enforced local management measures for the blue and red shrimp fishery require a 50-mm squared mesh (BOE 2018, APM/532/2018). Each haul was GPS-recorded with a start and end point, fishing time and gear width. These measurements were used to calculate the total swept area per haul in order to standardize species biomass and abundance values [21]. The sampling is designed to run a complete cycle throughout a calendar year so that the data are comparable annually, and the data analyzed in this study correspond to the years

2019–2021.

2.3. Analysis of the catch

The fishers sort the catch into two categories: commercial, i.e., individuals of commercial species to be sold in the fish auction, and discarded, i.e., all other organic and inorganic organisms and items. The discarded fraction includes individuals of non-commercial species and/or undersized or damaged individuals of commercial species – as well as natural debris and marine litter. All species of the commercial fraction, including fish, crustaceans and cephalopods among others, are identified and measured on board (total length, cephalothorax length and mantle length, respectively). From all the species identified, seven target species were chosen. Five are species of interest featured in the WMMAP regulation (EU Reg. 2019/1022) – the European hake (*Merluccius merluccius*), the red mullet (*Mullus barbatus*), the blue and red shrimp (*Aristeus antennatus*), the Norway lobster (*Nephrops norvegicus*), the deep-water rose shrimp (*Parapenaeus longirostris*) – whereas the spottail mantis shrimp (*Squilla mantis*), and the horned octopus (*Eledone cirrhosa*), while not mentioned in the regulation, are relevant in the economy of the area [17].

A subsample of at least 30 individuals of each target species is preserved in coolers and transported to the laboratory. Then, the individuals are stored at 4°C and processed the following day of the sampling. All individuals are measured and weighed, and their reproductive stage was assessed. Different biological data are acquired depending on the target species, detailed in Supplementary Table 1. For further information on the measurements taken on the other studied samples not reported in this study, see Annex I. The ICATMAR website (icatmar.cat) offers further information on all the studies done since 2019 and a data viewer with public and easy-access fisheries data [21].

2.4. Statistical analyses

For the purposes of this study, three different datasets were analyzed separately: all commercial species composition data, For the purposes of this study, three different datasets were analyzed separately: all commercial species composition data, and length frequency distribution, abundance and biomass of the target species.

The biomass of the commercial fraction of our sampling was calculated and standardized per square kilometer trawled. Data were square-root transformed in order to reduce the effect of extreme values, and the Bray-Curtis similarity index was calculated among hauls. Then, the data were represented in Non-Metric Multidimensional Scaling using the package vegan in R software [23], and statistically tested using PERMANOVA in R package *vegan* with 999 permutations. The three factors considered were season, zone, and depth. Pairwise comparisons between seasons, zones, and depths were also tested by subsetting the pair of factors to compare, where the function *p.adjust* (Bonferroni method) was applied in order to correct p-value of multiple comparisons. A similarity percentage analysis (SIMPER) was used to detect the species accounting for significant differences between depths.

Differences in the length frequency data obtained in our samplings for the seven target species were analyzed using a Kolmogorov-Smirnoff test by year, season, zone, and depth, with the R package *fishmethods* [23]. Only data from depths where each species is distributed were selected for the analyses (see Table 1) [24].

Differences in the abundance (individuals·km^{-2}) and biomass (kg·km^{-2}) for the seven target species were analyzed among years, seasons, areas, and depths using Generalized Linear Models (GLM), with the general formula as follows:

abundance ~ year + season + zone + depth

biomass ~ year + season + zone + depth

Data were not transformed and outliers were removed in a prior data validation process. Due to the zero-inflated nature of our data, the selected family distribution was negative binomial. The quantile-quantile (Q-Q) and Residuals vs. Predicted plots were explored through the package *DHARMa* to check for compliance of statistical assumptions and model fit. An analysis of the variance (ANOVA) was performed on the results of the model to clarify the significance of each factor. Then, pairwise comparisons were conducted for each pair of levels of each factor. The GLM analysis was done with the package *MASS* and the pairwise comparisons with *emmeans* [23].

Table 1
Number of individuals sampled every year for the seven target species, number of hauls where individuals of each species were analyzed, and depth strata where the species were distributed.

Species	Year	Number of individuals sampled	Number of hauls	Depth strata
Squilla mantis	2019	1862	18	Coastal delta shelf
	2020	942	12	Middle delta shelf
	2021	1500	14	
Mullus barbatus	2019	2181	56	Coastal delta shelf
	2020	1397	41	Middle delta shelf
				Deep shelf
Eledone cirrhosa	2019	910	68	Coastal delta shelf
	2020	696	58	Middle delta shelf
	2021	644	89	Deep shelf
				Upper slope
				Lower slope
Merluccius merluccius	2019	3849	116	Coastal delta shelf
	2020	2736	78	Middle delta shelf
	2021	4563	90	Deep shelf
				Upper slope
				Lower slope
Parapenaeus longirostris	2019	3324	63	Coastal delta shelf
	2020	3527	53	Middle delta shelf
	2021	4491	62	Deep shelf
				Upper slope
Nephrops norvegicus	2019	6166	46	Upper slope
	2020	4343	45	Lower slope
	2021	5011	42	
Aristeus antennatus	2019	9185	34	Lower slope
	2020	7650	28	
	2021	7336	28	

3. Results

3.1. Spatial structure of the catch composition

A nMDS representation of the sampling data (Fig. 2) showed a fair fit to the distinct groupings corresponding to the five different depth ranges. The PERMANOVA test detected significant differences among depths ($p = 0.001$), zones ($p = 0.001$), and seasons ($p = 0.001$). The species composition of the catch was significantly different among all depths, as detailed in Table 2A ($p < 0.01$ in all cases). Within the same depths, there were significant differences between the three zones (Table 2B). In particular, the deep shelf was different for each zone (north, center and south, $p < 0.01$ in all cases). The upper slope and the lower slope had significant differences between the north and the center zones ($p < 0.01$ in both cases). There were also significant dfferences among seasons within a same depth (Table 2C).

The SIMPER analysis identified the commercial species that characterize the different depths (Table 2). For example, the upper slope was characterized by the presence of *P. blennoides*, *N. norvegicus*, and *P. longirostris,* and the lower slope by *A. antennatus* (Table 2A). In

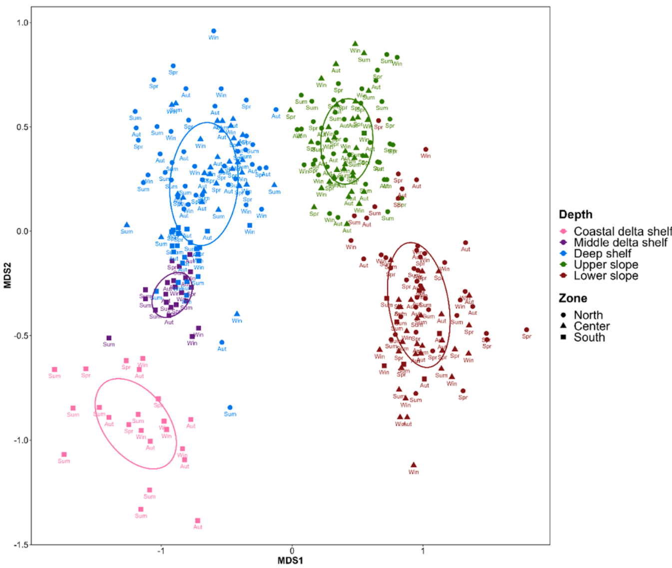

Fig. 2. Multidimensional ordination plot (nMDS; stress = 0.1517) of the single hauls. Colors represent depths (pink; coastal delta shelf, purple; middle delta shelf, blue; deep shelf, green; upper slope and red; lower slope); shapes represent zones (circles; north, triangles; center and squares; south), and letters represent seasons (Win; winter; Spr; spring, Aut; autumn and Sum; summer).

contrast, the shallower zones showed some overlapping, with the presence of the genus *Trachurus* as common species throughout the three ranges but with significant differences for other species (Table 2A). When the community composition was analized by depth and zone, the presence of *P. longirostris* and *M. surmuletus* characterized the landed fraction of the catch in the deep shelf of the north zone (Table 2B), while the dissimilarity in the northern samples is marked by the presence of a greater number of species. The upper and lower slopes of the center zone were characterized by the presence of *M. merluccius* and *G. melastomus*, respectively (Table 2B). As for the comparison by season, significant differences in species composition were observed at some depths, e.g., the presence of *M. merluccius* explaining a relevant part of the differences in the upper and lower slopes (Supplementary Table 4).

3.2. Length frequency comparison

The annual length-frequency distributions of the seven targeted species showed significant differences throughout the studied years for *E. cirrhosa* and *M. merluccius* (Fig. 3). In detail, between the years 2019 and 2020, *E. cirrhosa* showed a higher abundance of individuals under 200 g in 2020 (Kolmogorov-Smirnoff $p = 0.04$), and *M. merluccius* showed a higher abundance of individuals below the Minimum Conservation Reference Size (20 cm) in 2020 (Kolmogorov-Smirnoff $p = 0.01$).

The comparison of length frequency distribution across sampling depths showed significant differences in the case of *M. barbatus*, the coastal delta shelf presents a length frequency distribution that was significantly more centered around MCRS and L50 values than in other depths (Fig. 4). For *M. merluccius*, the upper and lower slope were significantly different from the rest of depth ranges, with a clear predominance of individuals above the MCRS and L50 (Fig. 4). In the case of *N. norvegicus*, individuals were significantly more evenly distributed across sizes in the lower slope, and the species showed a distribution with a median around 30 mm cephalothorax length (CL) in the upper slope (Supplementary Fig. 4). Finally, *P. longirostris* showed a distribution with values centered above the MCRS and L50 values in the upper slope, significantly different than the rest of depth ranges (Supplementary Fig. 4).

The pairwise size comparisons by depth for *M. merluccius* and *M. barbatus* are illustrated in Fig. 3. The overall trends and by factors, with detailed statistics and p-values for all tests is available in Supplementary Table 2. The comparison among seasons revealed significant differences in the length distribution data especially for *E. cirrhosa*, where all seasons were different except for autumn and winter, and *P. longirostris*, which seemed to present two types of distribution, one for spring and summer, with a predominance of larger individuals, and another for autumn and winter, with more individuals under the MCRS (Supplementary Table 2). Distributions were fairly homogenous throughout all seasons for *M. merluccius* and *N. norvegicus*, which only presented significant differences between spring and autumn (Supplementary Table 2). Regarding the analysis by zone, there were significant differences for *M. barbatus, E. cirrhosa*, *P. longirostris*, and *A. antennatus* for at least one pair of depths compared (Supplementary Table 2). All species had significant diferences for at least one of the season combinations studied.

3.3. Abundance and biomass

In the comparison among the three studied years, three species, *M. merluccius, P. longirostris*, and *A. antennatus*, showed significant differences through time, the two former for both abundance and biomass values, and the latter only for biomass values (Fig. 5, Supplementary Table 3). No significant differences (ANOVA $p > 0.05$; Supplementary Table 3) were found for the other studied species over time. All species showed significant differences in abundance and biomass values by depth strata, and among them, *M. barbatus N. norvegicus* did not show differences in abundance for any other factor (Supplementary Table 3, Annex II).

As for the analysis by season, abundance and biomass values were fairly stable across the data. Abundance of *S. mantis* in autumn (1041.89 ± 232.61 ind·km^{-2}) was significantly higher than in the spring (670.74 ± 187.36 ind·km^{-2}) and lower than in the summer (1744.91 ± 313.99 ind·km^{-2}; Fig. 6, see Supplementary Table 3 for p-values). As for biomass, *E. cirrhosa* showed significantly higher values in the winter (15.98 ± 2.69 kg·km^{-2}) than in the autumn (12.54 ± 2.34 kg·km^{-2}) and in the summer (6.90 ± 1.19 kg·km^{-2}). For *A. antennatus,* biomass was significantly higher in the summer (47.18 ± 9.72 kg·km^{-2}) than in the autumn (27.21 ± 4.97 kg·km-^{2}; Fig. 6; Supplementary Table 3).

Comparison among depth strata showed the most significant differences in all species. For *E. cirrhosa*, abundance and biomass values were significantly higher in the deep shelf (100 ind·km^{-2} and 20 kg·km^{-2}) and lower in the coastal delta shelf (5 ind·km^{-2} and 1 kg·km^{-2}; Fig. 6). In the case of *M. merluccius*, abundance and biomass showed significantly higher values in the deep shelf (1191 ind·km^{-2} and 58 kg·km^{-2}) than in all other strata except for the middle delta shelf. For *N. norvegicus* and *A. antennatus*, abundance and biomass showed an opposite trend, being significantly higher in the upper slope for the former (2184.58 ± 220.58 ind·km^{-2} and 49.26 ± 4.84 kg·km^{-2} in average) and in the lower slope for the latter (4120.03 ± 268.52 ind·km^{-2} and 74.78 ±4.94 kg·km^{-2}, ANOVA $p < 0.01$ in all cases).

4. Discussion

This study analyzes the spatial and temporal patterns affecting the key fishing resources exploited by the Catalan bottom trawling fleet, using data obtained from a newly implemented monitoring program along the Catalan coast. The dataset resulting from the monitoring program has proven to be generally comparable throughout the years and clearly reflects the variability through the seasons, zones and depth ranges for the targeted species. For instance, the commercial fraction of the catch of the continental slope shows predominance of a single species in the Center zone (*M. merluccius* in the upper slope, and *G. melastomus* in the lower slope), whereas in the North zone, the differences are explained by a group of species, and distinguished from the center by the presence of *N. norvegicus* in the upper slope and

Table 2
List of species contributing to the dissimilarity in the composition of the landed catch among levels of A: depth; and B: zone, obtained from SIMPER test. First two columns show the two levels of the factor that are significantly different. Spp 1 and 2 refer to the species that are most abundant in each level of reference. Dissimilarity refers to the total contribution of the species shown (in cumulative percentage) to the difference between levels 1 and 2 of each factor. p-value indicates the results of PERMANOVA test comparing each pair of levels.

A

Depths compared		Species accounting for differences			PERMANOVA
Depth 1	Depth 2	Spp 1	Spp 2	Dissimilarity	p-value
Coastal delta shelf	Middle delta shelf	*Pagellus erythrinus* *Trachurus mediterraneus* *Squilla mantis* *Sphyraena sphyraena* *Mullus barbatus*	*Merluccius merluccius* *Illex coindetii* *Trachurus trachurus* *Eledone cirrhosa*	46 %	< 0.01
Coastal delta shelf	Deep shelf	*Pagellus erythrinus* *Trachurus mediterraneus* *Squilla mantis*	*Trachurus trachurus* *Lophius budegassa* *Merluccius merluccius* *Mullus barbatus*	47 %	< 0.01
Coastal delta shelf	Upper slope	*Pagellus erythrinus* *Squilla mantis* *Trachurus mediterraneus*	*Phycis blennoides* *Nephrops norvegicus* *Micromesistius poutassou* *Parapenaeus longirostris*	48 %	< 0.01
Coastal delta shelf	Lower slope	*Pagellus erythrinus* *Squilla mantis* *Trachurus mediterraneus*	*Aristeus antennatus* *Phycis blennoides*	46 %	< 0.01
Middle delta shelf	Deep shelf	*Squilla mantis* *Eledone cirrhosa*	*Trachurus trachurus* *Lophius budegassa* *Merluccius merluccius* *Mullus barbatus* *Illex coindetii*	49 %	< 0.01
Middle delta shelf	Upper slope	*Merluccius merluccius* *Squilla mantis* *Eledone cirrhosa*	*Phycis blennoides* *Nephrops norvegicus* *Micromesistius poutassou* *Parapenaeus longirostris*	47 %	< 0.01
Middle delta shelf	Lower slope	*Merluccius merluccius* *Squilla mantis* *Illex coindetii* *Eledone cirrhosa*	*Aristeus antennatus* *Phycis blennoides*	46 %	< 0.01
Deep shelf	Upper slope	*Trachurus trachurus* *Lophius budegassa* *Mullus barbatus* *Merluccius merluccius*	*Phycis blennoides* *Nephrops norvegicus* *Parapenaeus longirostris*	55 %	< 0.01
Deep shelf	Lower slope	*Trachurus trachurus* *Merluccius merluccius* *Lophius budegassa* *Mullus barbatus*	*Aristeus antennatus*	50 %	< 0.01
Upper slope	Lower slope	*Nephrops norvegicus* *Phycis blennoides* *Micromesistius poutassou* *Parapenaeus longirostris*	*Aristeus antennatus*	60 %	< 0.01

B

Depths & zones compared		Species accounting for differences			PERMANOVA
Depth & zone 1	Depth & zone 2	Spp 1	Spp 2	Dissimilarity	p-value
Deep shelf North	Deep shelf Center	*Mullus barbatus* *Parapenaeus longirostris* *Trisopterus capelanus*	*Trachurus trachurus* *Lophius budegassa* *Illex coindetii* *Merluccius merluccius* *Eledone cirrhosa*	66 %	0.02
Deep shelf North	Deep shelf South	*Trachurus trachurus* *Mullus barbatus* *Illex coindetii* *Parapenaeus longirostris*	*Lophius budegassa* *Merluccius merluccius* *Eledone cirrhosa*	52 %	<0.01
Deep shelf Center	Deep shelf South	*Trachurus trachurus* *Merluccius merluccius* *Illex coindetii* *Mullus barbatus*	*Lophius budegassa* *Eledone cirrhosa*	54 %	<0.01
Upper slope North	Upper slope Center	*Phycis blennoides* *Nephrops norvegicus* *Micromesistius poutassou* *Parapenaeus longirostris*	*Merluccius merluccius*	59 %	<0.01
Lower slope North	Lower slope Center	*Aristeus antennatus* *Phycis blennoides* *Merluccius merluccius* *Micromesistius poutassou*	*Galeus melastomus*	66 %	<0.01

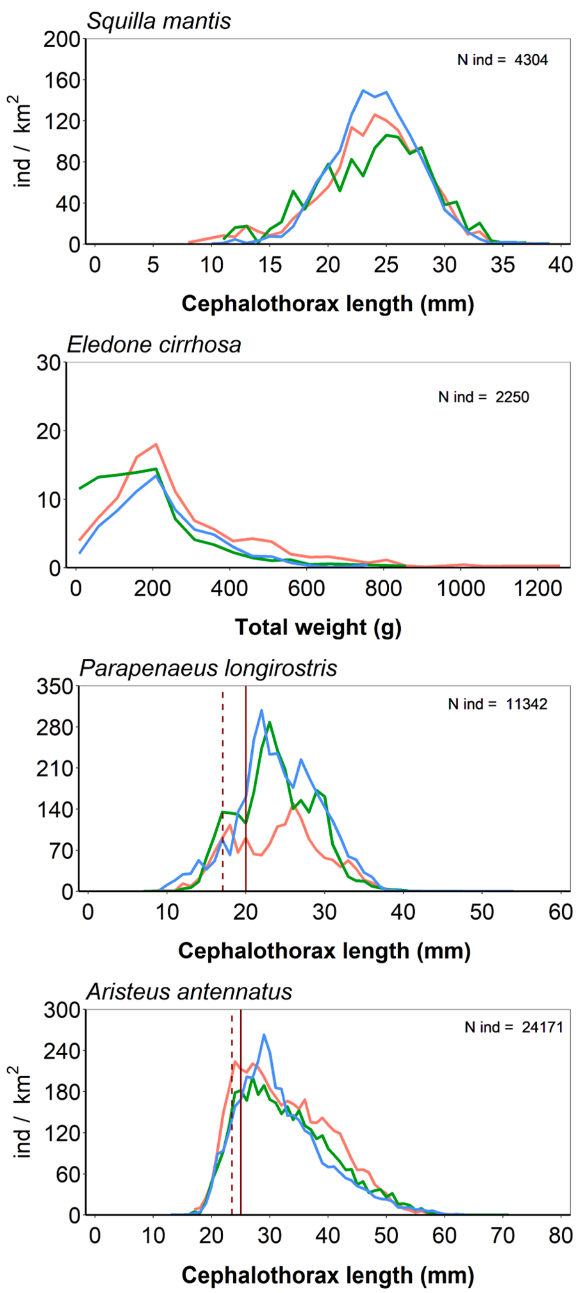

Fig. 3. Annual length-frequency distribution of seven target species for the years 2019 (red), 2020 (green), and 2021 (blue). Red line: Minimum Conservation Reference Size (MCRS). Red dashed line: size at first maturity obtained with ICATMAR data.

A. antennatus in the lower slope. The high abundance and biomass values for *A. antennatus* in the South zone correspond to the samplings in the lower slope, which is the depth of preference for this species. These results are of main importance because the collection of extensive and reliable data is the basis for fisheries assessment and the resulting datasets need to be up to scale with the particularities of each region [25, 26]. The design of a fisheries monitoring program should aim to collect data that reflect dynamics of both biological and spatio-temporal trends in different spatial extents and scales [27], as well as the seasonality that defines the changing fleet strategies throughout the year [28]. The locally-based monitoring program designed by ICATMAR and its data collection are capturing the particularities of the area, where fisheries are markedly multispecific and fleet behavior differs by area, being representative of local and regional characteristics that would be undetectable at a larger spatio-temporal scale monitoring.

The present sampling provides data on target species that are needed for stock assessment analysis, such as abundance, length frequency distributions or size at first maturity. The published information on these parameters in the Mediterranean Sea is scarce and often comes from one-time studies, and as such, does not support seasonal or inter-annual comparison (e.g. [29–31]). For example, the significant increase of *M. merluccius* individuals below L50 in 2020 found in this study gives a glimpse of the interannual variability of the recruitment of this species, which can be favored by environmental factors such as enhanced primary production or late winter low temperatures promoting egg and larval survival [32]. The parameters may also vary according to locations. For example, a study from the different GSA areas in the Mediterranean Sea determined that Sardinia (GSA 11) had the highest abundance and biomass for *M. merluccius* with 180,493 ind·km^{-2} and 4636 kg·km^{-2} [33], values much above the ones found in this study. These type of data may not only vary with environmental changes, including climate change [34,35], but also with high fishing pressure,

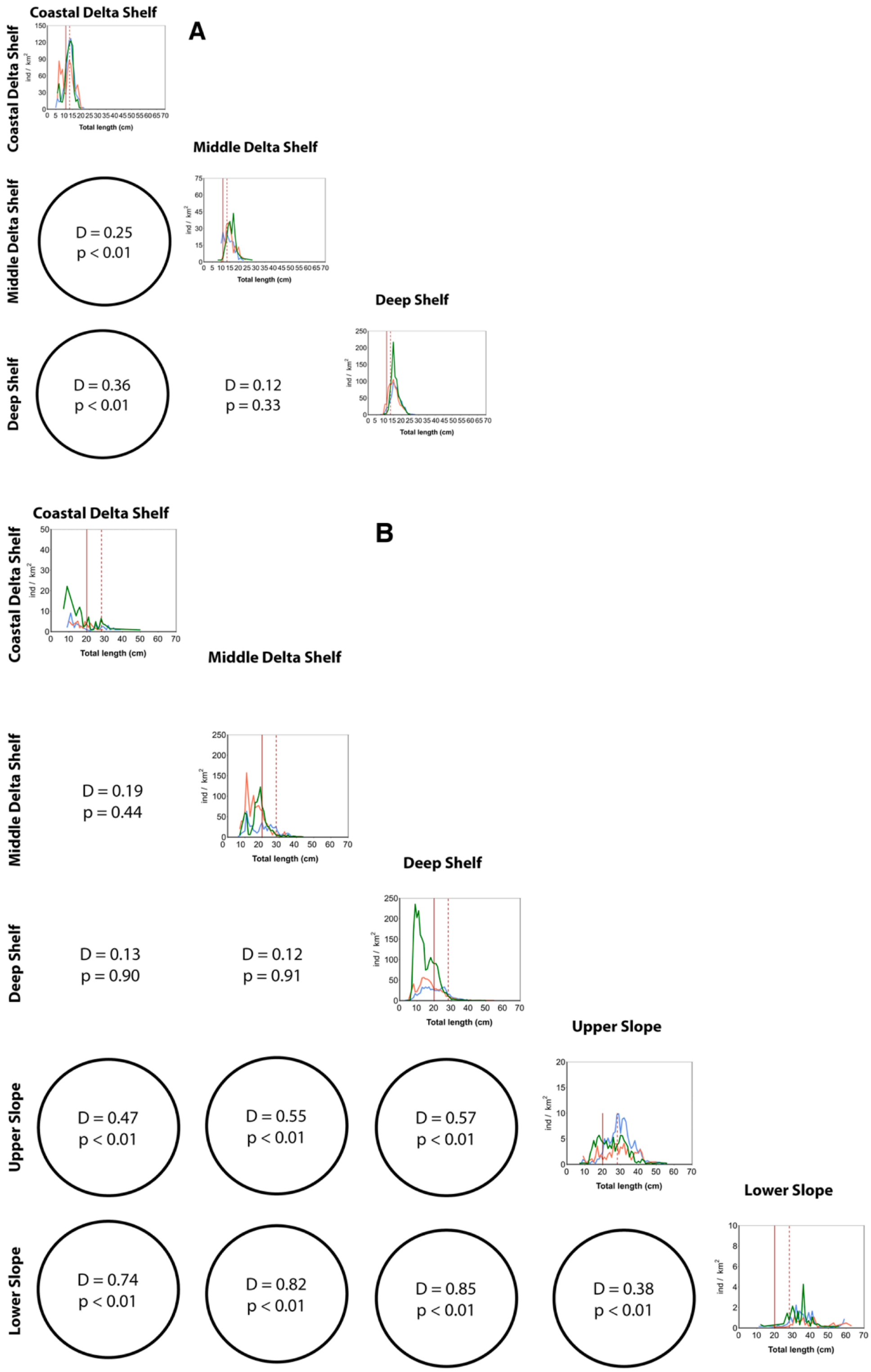

Fig. 4. Length-frequency distribution by depth for the years 2019–2021 for (A) *M. barbatus* and (B) *M. merluccius*. Red line: Minimum Conservation Reference Size (MCRS). Red dashed line: size at first maturity (L50) obtained with ICATMAR data. D: Kolmogorov's D statistic; p: p-value of the pairwise test. Circles indicate significant differences between a pair of depths.

which may entail a decrease in the size at first maturity (L50) of overexploited species [36,37]. For instance, the L50 for *N. norvegicus* inhabiting along the Catalan coast has been reduced in 5 mm compared to 1974 [37]. On the contrary, *M. barbatus* does not seem to have changed over time since a study in the Mediterranean (1994–2000) determined that most catches were composed of animals smaller than 15 cm [38] and the L50 has been determined within the range of 13 cm (for females) in different studies from different time periods [39–41].

The sampling on board bottom trawling vessels provides length data across the depth range for the studied species. However, some gaps on species population characteristics might be difficult to bridge when only using bottom trawling. This is the case of larger individuals of *M. merluccius,* which are missing from the sampling because they are caught by small-scale fisheries (longline and trammel nets) [42]. Also,

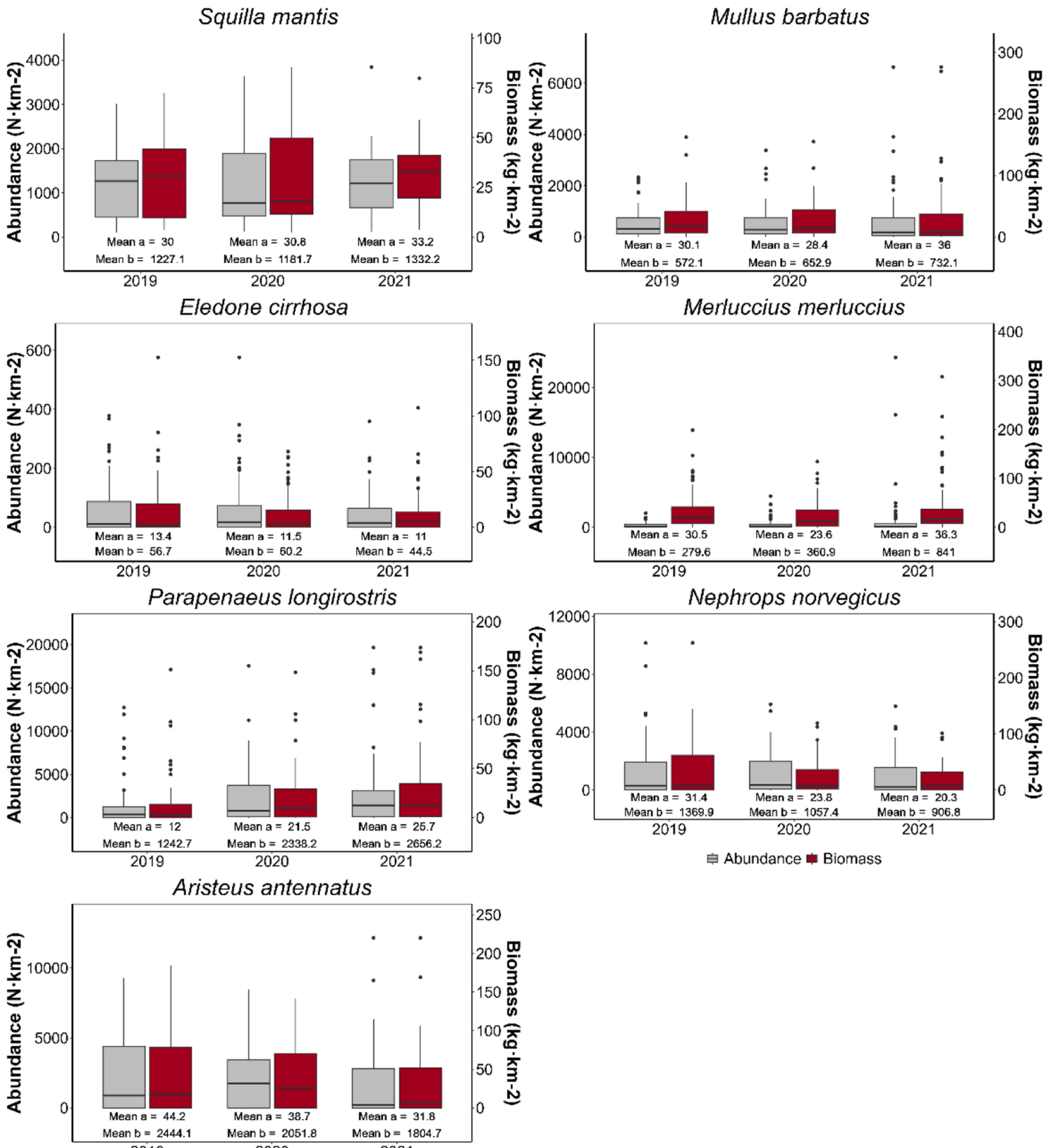

Fig. 5. Box plots showing the abundance (ind·km^{-2}, in gray) and biomass (kg·km^{-2}, in red) of the seven targeted species for the studied years (2019–2021). Mean a: mean abundance; Mean b: mean biomass.Regarding the different zones, biomass of *E. cirrhosa* was significantly lower in the center zone (9.49 ± 1.41 kg·km^{-2}) than in the north and south zones (11.60 ± 1.90 and 16.11 ± 2.20 kg·km^{-2} respectively; Fig. 6; ANOVA $p < 0.01$). Abundance of *A. antennatus* was significantly lower in the center zone (1624.83 ± 252.98 ind·km^{-2}; Fig. 6) than in the other zones, reaching a maximum in the south zone with 4515.84 ± 919.96 ind·km^{-2} (Fig. 6).

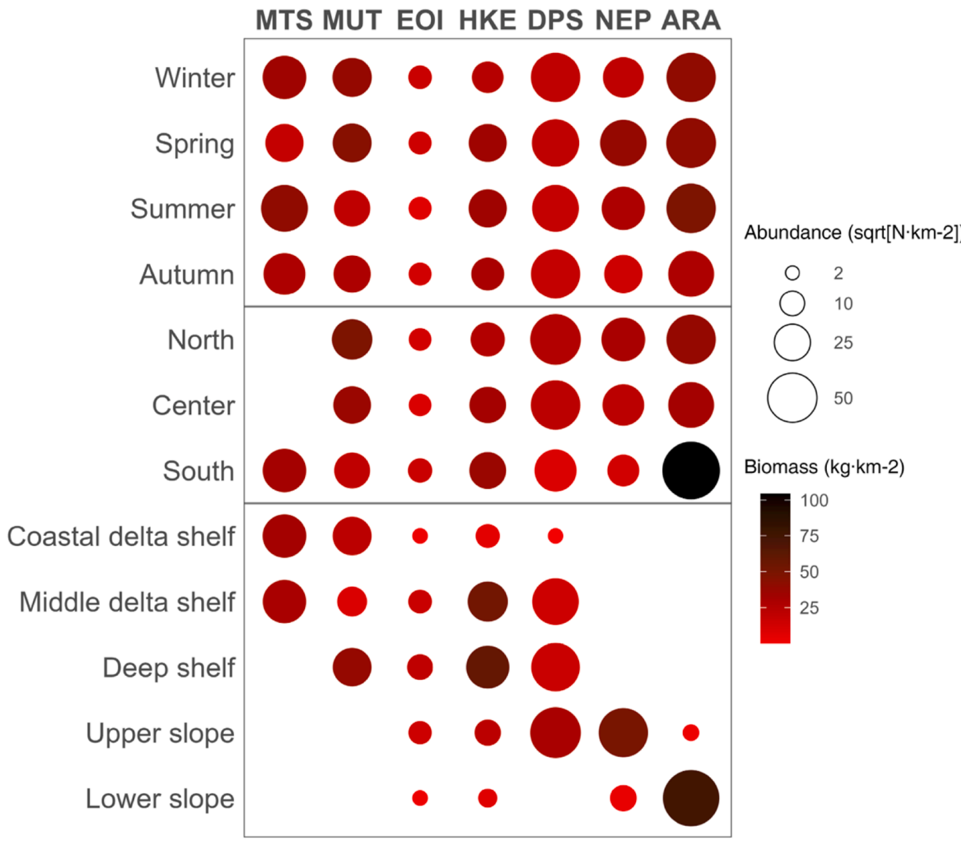

Fig. 6. Average abundance (in sqrt[N·km^{-2}]) and biomass (in kg·km^{-2}) for the seven studied species attending to factors season (top), zone (center), and depth (bottom). Size of the bubbles indicates abundance, and color indicates biomass. MTS: *S. mantis*; MUT: *M. barbatus*; EOI: *E. cirrhosa*; HKE: *M. merluccius*; DPS: *P. longirostris*; NEP: *N. norvegicus*; ARA: *A. antennatus*.

the depth range of *M. barbatus* includes shallower waters than those sampled in this study [43], and changes are already underway in the sampling structure to improve the coverage of this species, along with a plan to integrate small-scale fisheries in the monitoring program. In all, the monitoring program obtains biological information about where most of the species are distributed and provides proof that the fishing resources do not have a homogenous distribution in the Catalan margin. The potential of studying the relationship between fishing resources distribution and environmental variables using these continuous monitoring data has been layed out in the present study, but needs to be further explored in subsequent works that can address each species separately and in depth.

Besides information on target species, the monitoring program provides other key data for a better governance of the area including information on other commercial but non-target species, discards, marine litter or the identification of new species and resources. A recent study using ICATMAR data found an average discard ratio of 25 % for bottom trawling in the northern GSA 6 [8]. Discards assessment, considering both undersized individuals of commercial species and non-commercial species, is essential to evaluate the impact of fisheries in the ecosystems and implement ecosystem-based fisheries management actions [44]. In the framework of the Marine Strategy Framework Directive (MSFD) of the European Commission to achieve Good Environmental Status (GES) [46], an essential step is to establish monitoring programs for assessment enabling the state of the marine waters to be evaluated on a regular basis [47]

The current management strategies in the Mediterranean Sea derive from a North Atlantic fishery model, which are revised every year based on monitoring strategies from the EU Data Collection Framework (i.e., data from DCF MEDITS experimental cruises). However, regulations that are effective in the North Atlantic may not fit other fisheries in the European Union [45]. The Mediterranean Sea marine habitats are different than those from other European waters and may be defined by specific ecological characteristics [46]. Moreover, the Mediterranean has a typical seasonal pattern of temperate regions, with a thermocline from May to November and vertically mixed waters the rest of the year [47]. All these characteristics favor a spatial and temporal distribution of the marine resources, including key species for the bottom trawl fisheries [33,48,49]. Moreover, the northern GSA 6 is not only distinct by the distribution of its fishery resources, but also by its social component. The area is organized by fishery guilds, which were defined in the Middle Ages, and currently play a social and economic function in managing the resources [50]. These guilds can, as they have done in the past, implement local management strategies such as requiring a larger mesh size (50-mm instead of 40-mm square) for the blue and red shrimp fishery in Palamós (BOE 2018, APM/532/2018). The effectivity of local management strategies is only quantifiable with detailed long-term monitoring programs such as ICATMAR's, which began in 2019 and aims to continuously monitor the resources from the Catalan margin in the long term.

Managing the fishing resources of the Mediterranean is not an easy task. The species and fishing patterns are quite diverse, with landing sites widely distributed geographically [45] along a coastal region where fishing activity is one of the main socioeconomic activities in many small-medium localities. Although management strategies have been implemented for decades, their outcomes have not been as successful as expected for different reasons, including the disregard for scientific advice and the deficiencies of current national management plans [25]. Exhaustive locally-based scientific monitoring programs may be key to fisheries sustainability in the Mediterranean basin, especially when structured within more regionalized management areas that can accurately detect the changing patterns of fishing recources.

5. Conclusion

The main fishing resources exploited by the Catalan bottom trawling fleet, i.e. *S. mantis*, *M. barbatus*, *E. cirrhosa*, *M. merluccius*, *P. longirostris*, *N. norvegicus*, and *A. antennatus*, are not homogenously distributed in time or space throughout the northern GSA 6. An exhaustive continuous monitoring program allowed for higher spatial and temporal resolution of biological data on target species reflecting the dynamics of the fleet. We suggest that this type of sampling be included in Mediterranean areas to complement the current DCF program, so that fisheries can be managed evaluating the biology of the species along with the social component of the fisheries structure.

CRediT authorship contribution statement

Antoni Lombarte: Writing – review & editing, Conceptualization. **Alberto J Rico:** Writing – review & editing, Investigation. **Mariona Garriga-Panisello:** Writing – review & editing, Formal analysis. **Jordi Ribera-Altimir:** Writing – review & editing, Software. **Marta Blanco:** Writing – review & editing, Investigation, Formal analysis. **Joan Sala-Coromina:** Writing – review & editing, Visualization. **Marc Balcells:** Writing – review & editing, Investigation. **Alba Rojas:** Writing – review & editing, Investigation. **Ana I. Colmenero:** Writing – review & editing, Project administration. **Joan B. Company:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Marta Pujol-Baucells:** Writing – review & editing, Investigation. **Laura Recasens:** Writing – review & editing, Funding acquisition, Conceptualization. **Xènia Puigcerver-Segarra:** Writing – review & editing, Investigation. **Mireia G. Mingote:** Writing – review & editing, Investigation, Formal analysis. **Eve Galimany:** Writing – original draft, Investigation, Conceptualization. **John G. Ramírez:** Writing – review & editing, Conceptualization. **Marta Carreton:** Writing – original draft, Formal analysis, Conceptualization. **Mireia Silvestre:** Writing – review & editing, Investigation. **David Nos:** Writing – review & editing, Investigation. **Ricardo Santos-Bethencourt:** Writing – review & editing, Investigation. **Ferran Bustos:** Writing – review & editing, Investigation. **Cristina López-Pérez:** Writing – review & editing, Investigation.

Acknowledgements

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Annex I. – Laboratory protocols by species group

Crustaceans

The following data is taken from each of the 30 individuals of blue and red shrimp, deep-water rose shrimp, Norway lobster and spottail mantis shrimp fished and transported to the laboratory: cephalothorax length (mm), total weight (0.01 g), sex (male, female, or indeterminate), gonad weight (0.01 g) and sexual maturity for females. For the spottail mantis shrimp, sexual maturity stages are 1: immature/resting, 2: maturing, and 3: mature. For the other target crustaceans, the stages are defined as 1: immature, 2: resting, 3: maturing, 4: mature, 5: spawning. Other specific parameters measured include the presence of a spermatophore for the blue and red shrimp, the stage of the eggs for Norway lobster (1: just layed, 2: developing, 3: developed) and the stage of the female cement glands for the spottail mantis shrimp (1: immature/resting, 2: maturing, 3: mature).

Horned octopus

A sample of 30 individuals are taken for biological sampling. The measurements taken are dorsal mantle length (mm), total weight (0.1 g), sex (male or female), and sexual maturity (1: immature, 2: developing, 3: maturing, 4: mature, 5: spawning; 6: post spawning). For females, the presence of a spermatangium in the ovary is recorded.

European hake and red mullet

All individuals caught are measured (mm), 30 individuals for each category size are taken for biological sampling recording the following data: total length (mm), total weight (0.1 g), gutted weight (0.1 g), sex (male, female, or indeterminate), sexual maturity (1: immature, 2: resting, 3: maturing, 4: advanced maturation, 5: spawning; 6: post spawning), gonad weight (0.01 g), and, for the hake, liver weight (0.01 g), and stomach state (empty, full, evaginated empty, or evaginated full).

Discard fraction

The discarded fraction is preserved at −20ºC until further analysis, when all individuals are identified to the lowest possible taxonomic level, and individually mesasured and weighed using at least one decimal place (± 0.1 g), in all cases where possible. Each individual is measured (mm) following these criteria:

- fish: total length (anal length for macrurids)
- crustaceans: cephalothorax length
- cephalopods: dorsal mantle length (length to mid-eye for octopus)
- bivalves *Acanthocardia* spp. and *Venus nux*: total length
- gastropods: total length for *Galeodea* spp., length without siphon *Bolinus brandaris*

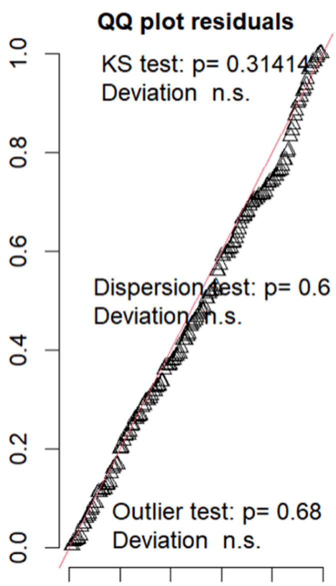
The natural debris, which include organic materials from both terrestrial and marine origin, are weighted (± 0.1 g) according to seven different categories: calcareous debris, marine algae, marine organic, marine plants, shells, terrestrial animals, and terrestrial plants. Marine litter, i.e. items with an anthropogenic origin either whole or broken, is classified following the application of Directive EU 2019/883 of the European Parliament and of the Council as regards to monitoring data methodologies and the format for reporting passively fished waste (EU 2022/92).

Annex II. – Information on the implementation of the General Linear Models

Model formulas in all cases are:
glm.nb(abundancia ~ Any + Estacio + ZonaPort + TipusDeFons, data = data.analysis)
glm.nb(biomassa ~ Any + Estacio + ZonaPort + TipusDeFons, data = data.analysis)
Information presented for each species:

- Quantile-Quantile (Q-Q) plot of the residuals
- Summary of the model
- Summary of the ANOVA analysis of the model

Any = year
Estacio = season
ZonaPort = zone
TipusDeFons = depth
MTS (*Squilla mantis*)
MTS – Abundance

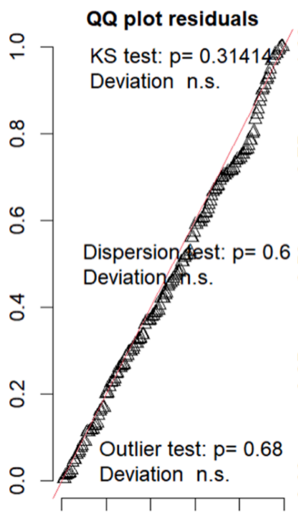



```
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.8733  -0.6669  -0.5399   0.1203   4.3948

Coefficients:
                      Estimate Std. Error z value Pr(>|z|)
(Intercept)            3.87104    0.15197  25.473  < 2e-16 ***
Any2020               -0.01914    0.14148  -0.135  0.89239
Any2021               -0.27715    0.14182  -1.954  0.05067 .
EstacioSpring          0.42935    0.16238   2.644  0.00819 **
EstacioSummer          0.46131    0.15716   2.935  0.00333 **
EstacioWinter          0.36378    0.16679   2.181  0.02918 *
ZonaPortNorth          0.27225    0.12162   2.239  0.02519 *
ZonaPortSouth          0.63203    0.22632   2.793  0.00523 **
TipusDeFonsUpper slope -5.96102   0.27504 -21.674  < 2e-16 ***
```

```
            Df Deviance Resid. Df Resid. Dev         F    Pr(>F)
NULL                          161    1635.72
Any          2    10.26       159    1625.46    5.1295  0.005919 **
Estacio      3    23.25       156    1602.21    7.7492 3.586e-05 ***
ZonaPort     2    36.41       154    1565.80   18.2070 1.238e-08 ***
TipusDeFons  1  1417.62       153     148.18 1417.6181 < 2.2e-16 ***
---
```

MTS – Biomass



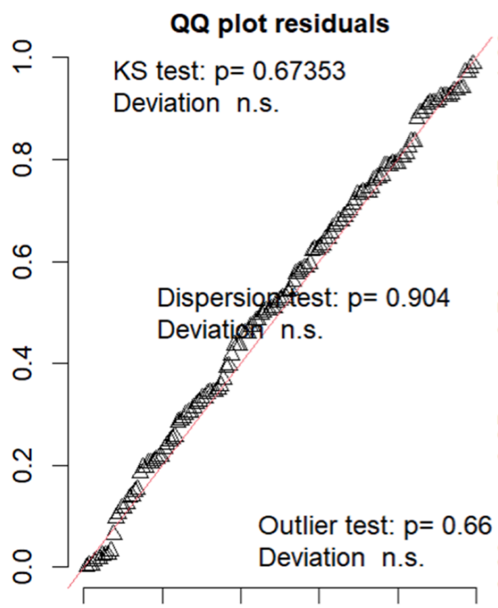

```
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.8733  -0.6669  -0.5399   0.1203   4.3948

Coefficients:
                      Estimate Std. Error z value Pr(>|z|)
(Intercept)            3.87104    0.15197  25.473  < 2e-16 ***
Any2020               -0.01914    0.14148  -0.135  0.89239
Any2021               -0.27715    0.14182  -1.954  0.05067 .
EstacioSpring          0.42935    0.16238   2.644  0.00819 **
EstacioSummer          0.46131    0.15716   2.935  0.00333 **
EstacioWinter          0.36378    0.16679   2.181  0.02918 *
ZonaPortNorth          0.27225    0.12162   2.239  0.02519 *
ZonaPortSouth          0.63203    0.22632   2.793  0.00523 **
TipusDeFonsUpper slope -5.96102    0.27504 -21.674  < 2e-16 ***

            Df Deviance Resid. Df Resid. Dev         F    Pr(>F)
NULL                          161    1635.72
Any          2    10.26       159    1625.46    5.1295  0.005919 **
Estacio      3    23.25       156    1602.21    7.7492 3.586e-05 ***
ZonaPort     2    36.41       154    1565.80   18.2070 1.238e-08 ***
TipusDeFons  1  1417.62       153     148.18 1417.6181 < 2.2e-16 ***
```

MUT (*Mullus barbatus*)

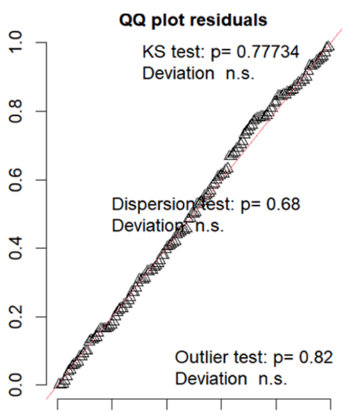
MUT – Abundance




```
Coefficients:
                                  Estimate Std. Error z value Pr(>|z|)    
(Intercept)                        6.33866    0.32397  19.566  < 2e-16 ***
Any2020                            0.17623    0.26952   0.654  0.51321    
Any2021                            0.22046    0.25743   0.856  0.39179    
EstacioSpring                      0.04430    0.31019   0.143  0.88644    
EstacioSummer                     -0.35967    0.29100  -1.236  0.21646    
EstacioWinter                      0.03199    0.31141   0.103  0.91819    
ZonaPortNorth                      0.32581    0.29851   1.091  0.27506    
ZonaPortSouth                     -0.06013    0.35409  -0.170  0.86515    
TipusDeFonsMiddle continental shelf -1.00063  0.38792  -2.579  0.00989 ** 
TipusDeFonsShallow continental shelf 0.46397  0.38769   1.197  0.23140    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
            Df Deviance Resid. Df Resid. Dev      F   Pr(>F)   
NULL                          144     196.69                   
Any          2   0.9370       142     195.76 0.4685 0.625946   
Estacio      3   2.0951       139     193.66 0.6984 0.552902   
ZonaPort     2   3.0748       137     190.59 1.5374 0.214939   
TipusDeFons  2  11.9065       135     178.68 5.9533 0.002597 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

MUT – Biomass

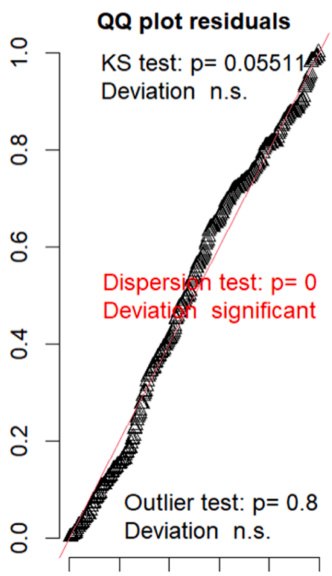


	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			144	202.27			
Any	2	1.1031	142	201.17	0.5516	0.57605	
Estacio	3	9.7242	139	191.45	3.2414	0.02106	*
ZonaPort	2	11.0080	137	180.44	5.5040	0.00407	**
TipusDeFons	2	9.0547	135	171.38	4.5273	0.01081	*

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

EOI (*Eledone cirrhosa*)

EOI – Abundance

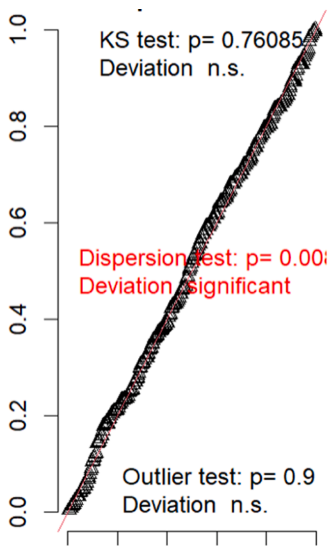



```
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.9163  -1.2590  -0.5383   0.1371   2.1786

Coefficients:
                                   Estimate Std. Error z value Pr(>|z|)
(Intercept)                         4.01198    0.33575  11.949  < 2e-16 ***
Any2020                             0.25906    0.26477   0.978   0.3279
Any2021                            -0.17995    0.25586  -0.703   0.4819
EstacioSpring                       0.12468    0.30074   0.415   0.6785
EstacioSummer                       0.03221    0.29000   0.111   0.9115
EstacioWinter                       0.55827    0.30731   1.817   0.0693 .
ZonaPortNorth                       0.59198    0.24813   2.386   0.0170 *
ZonaPortSouth                       0.70011    0.39835   1.758   0.0788 .
TipusDeFonsLower slope             -3.05241    0.28275 -10.796  < 2e-16 ***
TipusDeFonsMiddle continental shelf -0.71210   0.51928  -1.371   0.1703
TipusDeFonsShallow continental shelf -3.59826  0.53082  -6.779 1.21e-11 ***
TipusDeFonsUpper slope             -0.49707    0.28794  -1.726   0.0843 .
---
```

```
            Df Deviance Resid. Df Resid. Dev       F Pr(>F)
NULL                          306     440.76
Any          2    1.467       304     439.29  0.7337 0.4801
Estacio      3    0.544       301     438.75  0.1813 0.9092
ZonaPort     2    2.800       299     435.95  1.4001 0.2466
TipusDeFons  4  107.831       295     328.12 26.9577 <2e-16 ***
```

EOI – Biomass



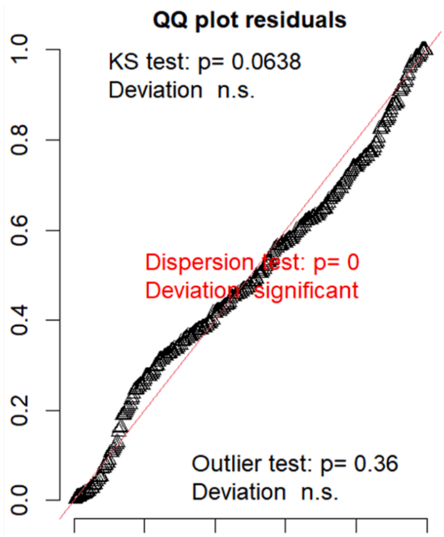

```
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.9882  -1.1476  -0.6200   0.1678   2.2960

Coefficients:
                                   Estimate Std. Error z value Pr(>|z|)
(Intercept)                         2.34101    0.28357   8.256  < 2e-16 ***
Any2020                             0.02047    0.22594   0.091  0.92782
Any2021                            -0.19020    0.21853  -0.870  0.38411
EstacioSpring                       0.18115    0.25581   0.708  0.47885
EstacioSummer                      -0.40058    0.25082  -1.597  0.11025
EstacioWinter                       0.71449    0.25960   2.752  0.00592 **
ZonaPortNorth                       0.59674    0.21191   2.816  0.00486 **
ZonaPortSouth                       1.02607    0.33302   3.081  0.00206 **
TipusDeFonsLower slope             -2.46035    0.24671  -9.973  < 2e-16 ***
TipusDeFonsMiddle continental shelf -0.53066   0.42802  -1.240  0.21505
TipusDeFonsShallow continental shelf -3.67572  0.49266  -7.461 8.59e-14 ***
TipusDeFonsUpper slope             -0.07642    0.23764  -0.322  0.74778

            Df Deviance Resid. Df Resid. Dev       F    Pr(>F)
NULL                          306     475.69
Any          2    1.042       304     474.65  0.5211  0.593861
Estacio      3   12.915       301     461.73  4.3051  0.004824 **
ZonaPort     2    9.396       299     452.34  4.6980  0.009114 **
TipusDeFons  4  125.094       295     327.24 31.2735 < 2.2e-16 ***
```

HKE (*Merluccius merluccius*)

HKE - Abundance

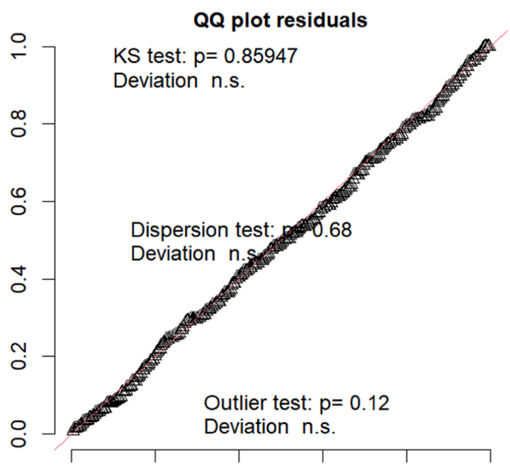



```
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.6884  -0.9005  -0.4472   0.0860   4.5245

Coefficients:
                                     Estimate Std. Error z value Pr(>|z|)
(Intercept)                           7.13280    0.21327  33.445  < 2e-16 ***
Any2020                              -0.29357    0.16847  -1.743  0.08141 .
Any2021                               0.43452    0.16194   2.683  0.00729 **
EstacioSpring                         0.08828    0.19060   0.463  0.64324
EstacioSummer                         0.11856    0.18367   0.646  0.51857
EstacioWinter                        -0.28002    0.19548  -1.432  0.15200
ZonaPortNorth                        -0.44619    0.15744  -2.834  0.00460 **
ZonaPortSouth                        -0.28780    0.25395  -1.133  0.25710
TipusDeFonsLower slope               -4.04502    0.17927 -22.564  < 2e-16 ***
TipusDeFonsMiddle continental shelf  -0.14167    0.33115  -0.428  0.66880
TipusDeFonsShallow continental shelf -2.74988    0.33221  -8.277  < 2e-16 ***
TipusDeFonsUpper slope               -2.26945    0.18380 -12.347  < 2e-16 ***
```

```
             Df Deviance Resid. Df Resid. Dev        F    Pr(>F)
NULL                           306     886.46
Any           2    53.69       304     832.78  26.8437 2.198e-12 ***
Estacio       3    17.29       301     815.49   5.7623 0.0006169 ***
ZonaPort      2    21.90       299     793.59  10.9522 1.752e-05 ***
TipusDeFons   4   420.57       295     373.02 105.1423 < 2.2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

HKE – Biomass



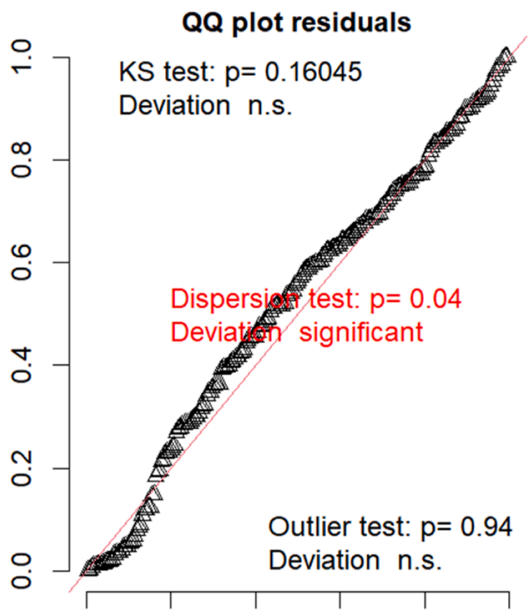

```
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.4334  -0.9599  -0.3346   0.3526   4.1049

Coefficients:
                                     Estimate Std. Error z value Pr(>|z|)
(Intercept)                           4.46473    0.17659  25.284  < 2e-16 ***
Any2020                              -0.44871    0.14111  -3.180  0.00147 **
Any2021                              -0.04998    0.13486  -0.371  0.71092
EstacioSpring                        -0.19372    0.15886  -1.219  0.22267
EstacioSummer                        -0.10969    0.15310  -0.716  0.47370
EstacioWinter                        -0.38082    0.16359  -2.328  0.01991 *
ZonaPortNorth                        -0.17407    0.13125  -1.326  0.18476
ZonaPortSouth                        -0.18820    0.21059  -0.894  0.37147
TipusDeFonsLower slope               -2.11879    0.15053 -14.076  < 2e-16 ***
TipusDeFonsMiddle continental shelf  -0.03761    0.27227  -0.138  0.89013
TipusDeFonsShallow continental shelf -2.27397    0.28569  -7.959 1.73e-15 ***
TipusDeFonsUpper slope               -1.02408    0.15166  -6.753 1.45e-11 ***
```

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			306	617.46			
Any	2	9.361	304	608.10	4.6803	0.009276	**
Estacio	3	4.533	301	603.56	1.5109	0.209383	
ZonaPort	2	7.069	299	596.49	3.5347	0.029166	*
TipusDeFons	4	223.235	295	373.26	55.8088	< 2.2e-16	***

DPS (*Parapenaeus longirostris)*

DPS - Abundance

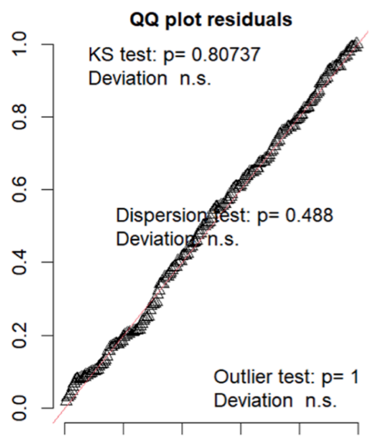



```
Deviance Residuals:
     Min        1Q    Median        3Q       Max
-2.37545  -1.13508  -0.49433   0.03751   2.28111

Coefficients:
                                      Estimate Std. Error z value Pr(>|z|)
(Intercept)                           7.261253   0.381225  19.047   <2e-16 ***
Any2020                               0.860502   0.313151   2.748   0.0060 **
Any2021                               1.012899   0.298831   3.390   0.0007 ***
EstacioSpring                        -0.405986   0.353758  -1.148   0.2511
EstacioSummer                        -0.591107   0.340811  -1.734   0.0828 .
EstacioWinter                         0.249364   0.361672   0.689   0.4905
ZonaPortNorth                        -0.089212   0.302402  -0.295   0.7680
ZonaPortSouth                        -0.296081   0.465391  -0.636   0.5246
TipusDeFonsMiddle continental shelf   0.006816   0.549839   0.012   0.9901
TipusDeFonsShallow continental shelf -6.340271   0.567479 -11.173   <2e-16 ***
TipusDeFonsUpper slope                0.282935   0.294407   0.961   0.3365
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			223	352.18			
Any	2	7.158	221	345.02	3.5789	0.02791	*
Estacio	3	1.914	218	343.10	0.6381	0.59038	
ZonaPort	2	6.904	216	336.20	3.4518	0.03169	*
TipusDeFons	3	64.047	213	272.15	21.3491	8.019e-14	***

DPS – Biomass



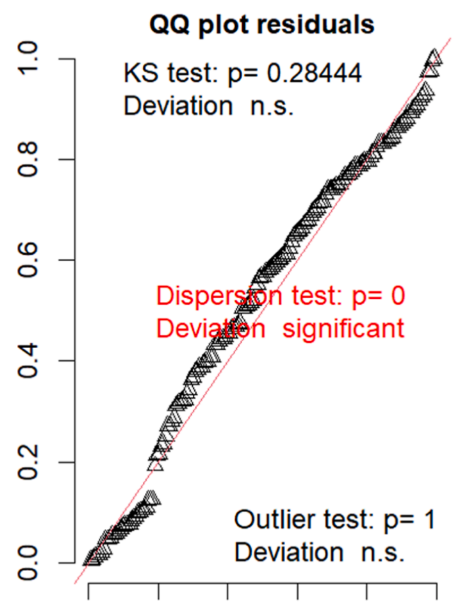

```
Deviance Residuals:
     Min        1Q    Median        3Q       Max
-2.11697  -1.21691  -0.33352   0.07183   2.22252

Coefficients:
                                     Estimate Std. Error z value Pr(>|z|)
(Intercept)                           2.24790    0.30830   7.291 3.07e-13 ***
Any2020                               0.60738    0.25906   2.345 0.019049 *
Any2021                               0.86439    0.24687   3.501 0.000463 ***
EstacioSpring                        -0.19093    0.29032  -0.658 0.510758
EstacioSummer                        -0.21692    0.28231  -0.768 0.442266
EstacioWinter                         0.05585    0.29864   0.187 0.851664
ZonaPortNorth                         0.10640    0.23874   0.446 0.655827
ZonaPortSouth                        -0.07983    0.36958  -0.216 0.828979
TipusDeFonsMiddle continental shelf  -0.02725    0.43738  -0.062 0.950321
TipusDeFonsShallow continental shelf -5.95250    1.22633  -4.854 1.21e-06 ***
TipusDeFonsUpper slope                0.73888    0.23237   3.180 0.001474 **
```

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			223	350.74			
Any	2	11.058	221	339.69	5.5291	0.0039697	**
Estacio	3	1.239	218	338.45	0.4131	0.7435792	
ZonaPort	2	18.010	216	320.44	9.0052	0.0001228	***
TipusDeFons	3	67.680	213	252.76	22.5600	1.339e-14	***

NEP (*Nephrops norvegicus*)

NEP – Abundance

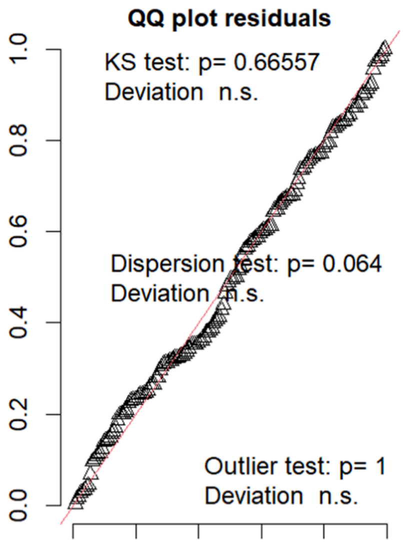



```
Deviance Residuals:
    Min       1Q    Median       3Q      Max
-2.1348  -1.1307  -0.4064   0.2111   3.3648

Coefficients:
                       Estimate Std. Error z value Pr(>|z|)
(Intercept)             4.41853    0.36189  12.209   <2e-16 ***
Any2020                -0.04122    0.32197  -0.128   0.8981
Any2021                -0.18183    0.31519  -0.577   0.5640
EstacioSpring          -0.01763    0.36011  -0.049   0.9610
EstacioSummer           0.23411    0.35530   0.659   0.5100
EstacioWinter           0.07757    0.37566   0.206   0.8364
ZonaPortNorth           0.48969    0.26846   1.824   0.0681 .
ZonaPortSouth          -0.13535    0.63739  -0.212   0.8318
TipusDeFonsUpper slope  2.99362    0.26185  11.433   <2e-16 ***
```

```
            Df Deviance Resid. Df Resid. Dev       F Pr(>F)
NULL                          161     304.42
Any          2    1.860       159     302.56  0.9299 0.3946
Estacio      3    5.838       156     296.72  1.9460 0.1198
ZonaPort     2    4.278       154     292.44  2.1392 0.1178
TipusDeFons  1   94.530       153     197.91 94.5304 <2e-16 ***
```

NEP – Biomass



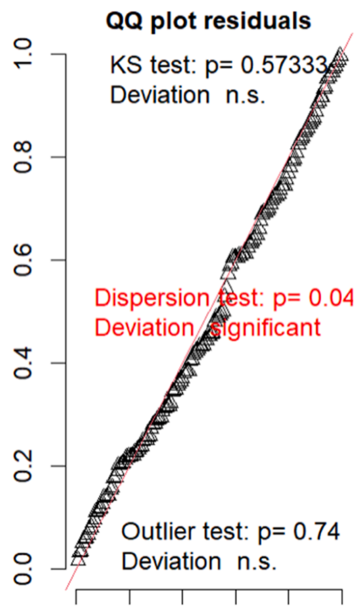

```
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.4361  -1.3921  -0.4951   0.2631   4.4912

Coefficients:
                       Estimate Std. Error z value Pr(>|z|)
(Intercept)             0.79684    0.27648   2.882  0.00395 **
Any2020                -0.06802    0.24035  -0.283  0.77716
Any2021                -0.16964    0.23514  -0.721  0.47063
EstacioSpring           0.04397    0.26914   0.163  0.87023
EstacioSummer           0.25512    0.26492   0.963  0.33554
EstacioWinter           0.05120    0.28185   0.182  0.85584
ZonaPortNorth           0.39170    0.20061   1.953  0.05087 .
ZonaPortSouth           0.10471    0.49544   0.211  0.83262
TipusDeFonsUpper slope  2.84207    0.19637  14.473  < 2e-16 ***
```

```
            Df Deviance Resid. Df Resid. Dev        F    Pr(>F)
NULL                          161     383.87
Any          2    4.090       159     379.78   2.0452  0.129360
Estacio      3   12.038       156     367.74   4.0127  0.007254 **
ZonaPort     2    3.809       154     363.93   1.9045  0.148890
TipusDeFons  1  168.622       153     195.31 168.6219 < 2.2e-16 ***
```

ARA (*Aristeus antennatus*)

ARA – Abundance

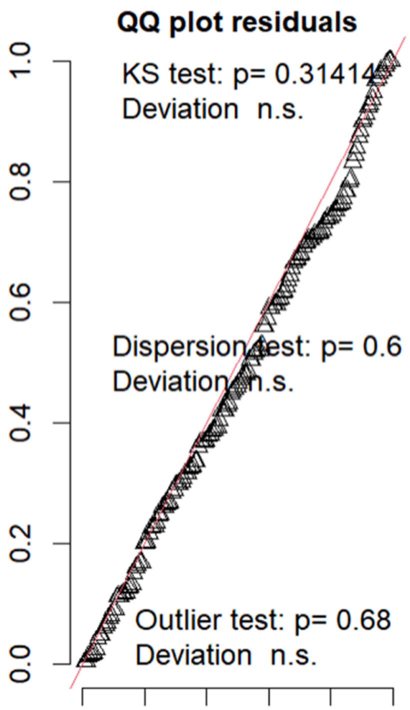



```
Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.65595  -1.20445  -0.79044  -0.07024   2.19567

Coefficients:
                       Estimate Std. Error z value Pr(>|z|)
(Intercept)              7.5889     0.4357  17.417  < 2e-16 ***
Any2020                  0.6946     0.3873   1.793 0.072946 .
Any2021                 -1.2606     0.3825  -3.295 0.000983 ***
EstacioSpring           -0.4053     0.4360  -0.930 0.352578
EstacioSummer            0.3028     0.4302   0.704 0.481560
EstacioWinter           -0.2256     0.4540  -0.497 0.619175
ZonaPortNorth            2.0436     0.3260   6.269 3.64e-10 ***
ZonaPortSouth            2.5018     0.7541   3.318 0.000908 ***
TipusDeFonsUpper slope  -6.8163     0.3171 -21.494  < 2e-16 ***
---
```

```
            Df Deviance Resid. Df Resid. Dev        F Pr(>F)
NULL                          161     377.26
Any          2    0.707       159     376.55   0.3536 0.7022
Estacio      3    1.031       156     375.52   0.3438 0.7936
ZonaPort     2    2.362       154     373.16   1.1809 0.3070
TipusDeFons  1  208.852       153     164.30 208.8516 <2e-16 ***
```

ARA – Biomass




```
Deviance Residuals:
    Min       1Q    Median      3Q      Max
-2.8733  -0.6669  -0.5399   0.1203   4.3948

Coefficients:
                      Estimate Std. Error z value Pr(>|z|)
(Intercept)            3.87104    0.15197  25.473  < 2e-16 ***
Any2020               -0.01914    0.14148  -0.135  0.89239
Any2021               -0.27715    0.14182  -1.954  0.05067 .
EstacioSpring          0.42935    0.16238   2.644  0.00819 **
EstacioSummer          0.46131    0.15716   2.935  0.00333 **
EstacioWinter          0.36378    0.16679   2.181  0.02918 *
ZonaPortNorth          0.27225    0.12162   2.239  0.02519 *
ZonaPortSouth          0.63203    0.22632   2.793  0.00523 **
TipusDeFonsUpper slope -5.96102   0.27504 -21.674  < 2e-16 ***
```

```
            Df Deviance Resid. Df Resid. Dev         F    Pr(>F)
NULL                          161    1635.72
Any          2    10.26       159    1625.46    5.1295  0.005919 **
Estacio      3    23.25       156    1602.21    7.7492 3.586e-05 ***
ZonaPort     2    36.41       154    1565.80   18.2070 1.238e-08 ***
TipusDeFons  1  1417.62       153     148.18 1417.6181 < 2.2e-16 ***
```

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2024.106512.

Data availability

Data will be made available on request.

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