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Characterization of discards along a wide bathymetric range from a trawl fishery in the NW Mediterranean

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ABSTRACT

Discards represent a loss of natural resources and negatively affect the sustainability of fisheries. Information on discards, such as diversity and size of the species discarded is essential to better manage trawl fisheries. Thus, this study aims to gain knowledge on discards from the Catalan bottom trawl fisheries in the NW Mediterranean Sea to offer information needed for fisheries management. Discard ratios, species composition of discards and lengths of the discards were analyzed from data collected on board commercial trawlers, from November 2018 to December 2020 and analyzed by depth, zone, and season. Discard ratio varied among depths from 30.5% in the shallowest depth (20 – 70 m) to 14.3% in the deepest (400–700 m), with depth being the main factor determining the species composition of discards. This study also focused on the discards of six main commercial species, i.e. European hake (*Merluccius merluccius*), red mullet (*Mullus barbatus*), black-bellied angler (*Lophius budegassa*), poor cod (*Trisopterus capelanus*), deep-water pink shrimp (*Parapenaeus longirostris*) and Norway lobster (*Nephrops norvegicus*). The length at which 50% of individuals were discarded (L_{50d}) was lower than the Length at First Maturity (LFM) and the Minimum Conservation Reference Size (MCRS) for the six species. These findings provide relevant information to comply with the Marine Strategy Framework Directive's (EU Directive 2008/56/EC) ecosystem approach to fisheries and to evaluate the implementation of measures for fisheries' best management practices, such as gear selectivity and spatial planning.

1. Introduction

Discards are the part of the total catch brought on board but returned to the sea, dead or alive, for different reasons including economic, legal, or personal considerations (Alverson et al., 1994). Commonly, discarded species may have no commercial interest or may be valuable species that are unmarketable (i.e. undersized or damaged individuals). Discarding is a common practice in commercial fisheries, especially in trawl fisheries, having an important impact on ecosystem dynamics (Bellido et al., 2011; Matsuoka, 2008; Muntadas et al., 2014; Sánchez et al., 2004). In this sense, quantification of discards is a main issue to fisheries management because it is considered a source of uncertainty for fisheries stock assessment models and decision-making, as well as a factor affecting biodiversity and community structure (Hall et al., 2000; Hall and Mainprize, 2004; Hilborn, 2011). This global concern led the European Commission to adopt management strategies to reduce or avoid discards in all European fisheries (EU Reg. 1380/2013). In this context, it is important to consider the high variability of discards, which depend on multiple factors such as depth, seabed characteristics, fishing methods, gear type, cultural factors, and geographic area (Despoti et al., 2020; Feekings et al., 2012; Gorelli et al., 2016; Grazia Pennino et al., 2014).

The discarded fraction of the catch follows the European regulation of discards. According to EU Reg. 2019/1241 the main target species have a Minimum Conservation Reference Size (MCRS hereinafter), thus all individuals measuring below this size are considered discards. This law specified that these types of discards should also be landed at port, establishing a landing obligation for the individuals below the MCRS. The goal of this legislation for European waters was that, in the long run, this obligation would promote fishers to adopt more selective fishing practices by avoiding areas or seasons associated with high quantities of unwanted catch (Despoti et al., 2020). Therefore, it is important to have

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good assessments of the discarded species and individuals regulated by their MCRS (Despoti et al., 2020; Tsagarakis, 2017; Uhlmann et al., 2019). The discarded fraction of the catch though, also includes non-commercial species. Thus discard assessments, considering both undersized and non-commercial species, are essential to evaluate the impact of the fishery on the ecosystems and implement ecosystem based fisheries' management actions (Hilborn, 2011).

The Catalan continental margin (NW Mediterranean Sea), which lays within the FAO subarea GSA 6 as defined by the General Fisheries Commission for the Mediterranean (FAO-GFCM), is a good area to study discards as it has a wide range of environmental characteristics and complex oceanographic processes (Lloret et al., 2001; Romano et al., 2017; Tecchio et al., 2013). Among all fisheries, the bottom trawl fishery is the most important one in terms of revenues and the second most important in landings (ICATMAR, 2021). The Catalan bottom trawling fleet is composed by 222 fishing vessels, which average total length is 19.5 m (Supplementary Table S1). Many studies reported the high negative impact on marine resources of this fleet (Muntadas et al., 2014; Sánchez et al., 2000) but the Catalan bottom trawling fishery has a high socio-economic importance with a total revenue of € 55 million and 7854 t landed in 2019, thus it is the livelihood of thousands of families (Supplementary Table S1). In order to consider information provided by discards to better manage fisheries, the European Commission approved the EU Reg. 2019/1241 encouraging the development of pilot projects to create a system of full documentation of catches and discards based on measurable objectives and targets. Therefore, the goal of this study is to analyze the discards of the Catalan trawling fleet for further management actions. This analysis includes a study of the spatio-temporal variability of discard ratios and species composition, a comparison between the landed (commercial) and discarded catch, and an assessment of the discards by length by the Catalan bottom trawling fleet.

2. Materials and methods

2.1. Sampling

Data were collected from November 2018 to December 2020 on board registered fishing vessels from the Catalan trawling fleet. The main commercial target species are distributed at different depths thus four depth strata were defined covering the whole area where the trawling fleet operates regularly, i.e. shallow shelf (20–70 m depth), shelf (70–200 m depth), upper slope (200–400 m depth) and lower slope (400–700 m depth). These depth strata, along with coastal length and the oceanographic features occurring in the Catalan sea (Clavel-Henry et al., 2021) were used to define three zones, corresponding with the traditional Catalan fisheries' divisions (locally called mar de llevant, mar de ponent and delta de l'Ebre). Samplings were carried out from the main commercial ports of the three zones: i) north, including the ports of Roses, Palamós, Blanes, and Arenys de Mar, ii) south, including the ports of Barcelona, Vilanova i la Geltrú, and Tarragona, iii) Ebre delta, including the ports of l'Ametlla de Mar and Sant Carles de la Ràpita, the shallowest zone of them all (Fig. 1).

Data were collected from each port seasonally, with a total of 213 hauls from 13 different bottom trawlers which represent the different types of trawlers in the Catalan fleet (Table 1). The start and end positions of each haul was recorded with a GPS as well as the horizontal opening of the net's mouth, allowing for the calculation of the swept area in order to standardize biomass and abundance. Depth was estimated by averaging the depth values between the start and end points of each haul. Mesh size was as established by the law, i.e. 40-mm square-mesh everywhere but in Palamós lower slope, which was 50-mm squared-mesh for the blue and red shrimp fishery. After each haul, fishers sorted the catch on board into two categories, landed catch (species with commercial interest to be sold in the fish auction) and

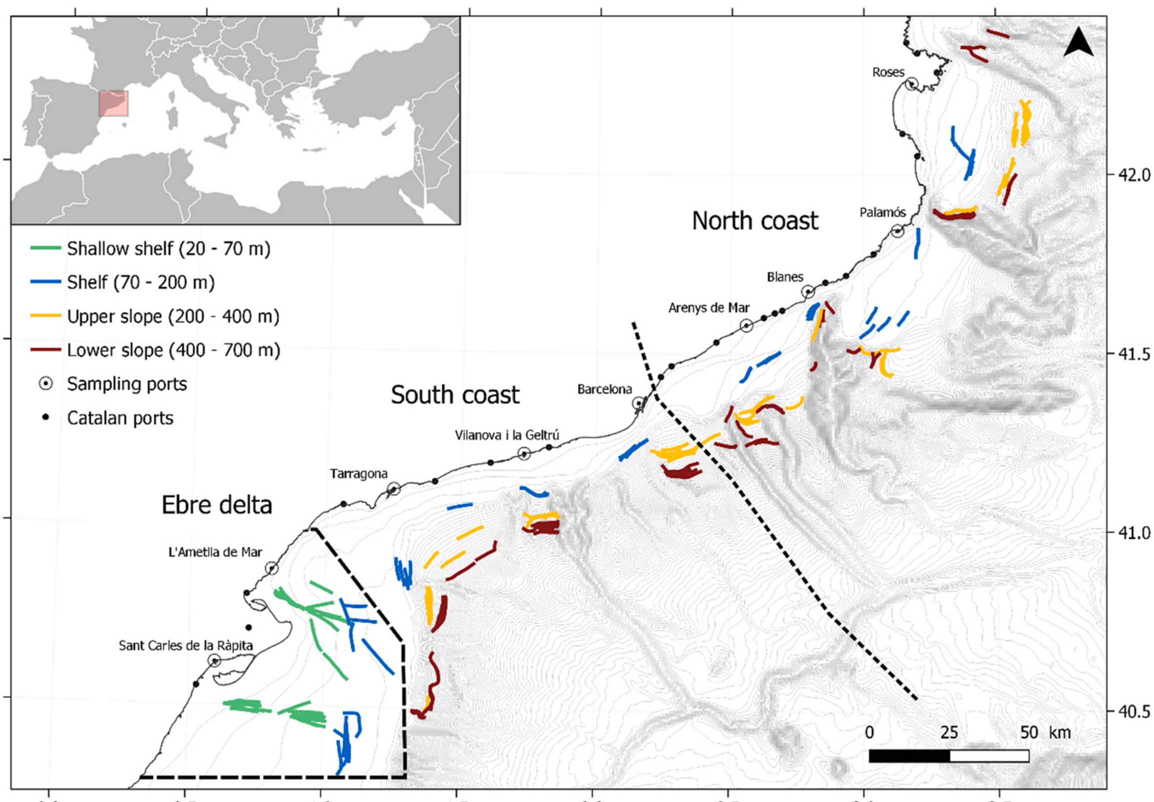

Fig. 1. Map plotting the studied area (Catalan coast) indicating zones (North and South zones and Ebre delta) and fishing ports. Each colored line represents a fishing track, with colors indicating a depth stratum, as indicated in the legend.

Table 1
Characteristics of all samplings by zones, seasons, and depths. Area sampled (km^2) is the sum of the area trawled in each haul. GT: vessel gross tonnage (t), Length: overall vessel length (m). ([a]) Total number of hauls and total area sampled. ([b]) Total number of different trawlers which participated in the sampling.

Zone	Season	Depth	Hauls (number)	Trawlers (number)	Area sampled (km^2)	Average GT (t)	Average length (m)
North coast	Winter	Shelf	4	3	0.32	63.10	21.02
		Upper slope	4	3	0.40	63.10	21.02
		Lower slope	4	3	0.33	63.10	21.02
	Spring	Shelf	8	4	0.96	66.05	21.26
		Upper slope	9	4	1.72	66.05	21.26
		Lower slope	8	4	1.49	66.02	21.84
	Summer	Shelf	8	5	0.91	71.59	22.02
		Upper slope	8	5	1.42	71.59	22.02
		Lower slope	7	5	1.44	71.56	22.48
	Fall	Shelf	11	5	1.37	71.59	22.02
		Upper slope	11	5	1.78	71.59	22.02
		Lower slope	10	5	1.87	71.56	22.48
South coast	Winter	Shelf	5	3	0.65	99.37	23.96
		Upper slope	6	4	0.92	97.82	24.00
		Lower slope	7	4	1.96	97.82	24.00
	Spring	Shelf	5	2	0.67	104.31	23.54
		Upper slope	5	2	0.93	104.31	23.54
		Lower slope	5	2	0.92	104.31	23.54
	Summer	Shelf	5	3	0.72	99.37	23.96
		Upper slope	5	3	1.04	99.37	23.96
		Lower slope	8	4	2.36	97.82	24.00
	Fall	Shelf	7	3	1.00	99.37	23.96
		Upper slope	9	4	1.51	91.89	23.62
		Lower slope	10	5	2.42	92.14	23.72
Ebre delta	Winter	Shallow shelf	6	2	1.15	71.90	22.81
		Shelf	3	2	0.66	71.90	22.81
	Spring	Shallow shelf	6	1	0.65	43.97	21.74
		Shelf	3	1	0.37	43.97	21.74
	Summer	Shallow shelf	11	2	1.96	71.90	22.81
		Shelf	3	2	0.39	71.90	22.81
	Fall	Shallow shelf	8	2	1.19	71.90	22.81
		Shelf	4	2	0.57	71.90	22.81
All zones			213[a]	13[b]	36.05[a]	78.88	22.71

discarded catch (species with no commercial interest and/or undersized or damaged individuals of a commercial species). Some species were identified and studied onboard whereas others were both, studied on board and preserved in coolers to transport to the laboratory for further analysis. In detail, the commercial fractions of fishes, crustaceans, and cephalopods were identified on board and their total length, total cephalothorax length, and mantle length were measured, respectively. For the individuals taken to the laboratory, either the total sample or a subsample was studied, depending on the quantity of both the commercial and discarded catch. The samples were then identified to species level or to the smallest possible taxonomic level and weighed (± 1 g).

2.2. Discards analysis

The analyses carried out on the total annual discards were based on the discards studied from each haul.

First, the discard ratio by haul was calculated using the following equation:

$$Discard\quad ratio = \frac{Discards\quad weight}{Discards\quad weight + Landed\quad weight} * 100$$

To scale up the total weight discarded each year by the Catalan bottom trawling fleet, the calculated mean discard ratio was used along with data from official sources for the total landed catch, including weight, registered in all ports in Catalonia (Supplementary Table S1).

Differences in the discard ratios (%), the discarded biomass (kg km^{-2}), and the number of species discarded were analyzed among seasons, zones, and depths using a Generalized Linear Model (GLM). The factor depth was nested to zone because not all depths were present in all zones. The selected family error distribution was "quasi-poisson". The choice for the most appropriate link function and error distribution was made based on residual analyses. The goodness of the fitted model was tested with a Chi-Squared test based on residual deviance and degrees of freedom (significance level $\alpha = 0.05$). The GLM analysis was done with R v3.6.3 package *mgcv* and pairwise comparison with the package *emmeans* (R, 2013). In order to describe the difference between the levels of the factors tested, the median was used instead of the mean because the data did not have a normal distribution.

2.3. Species composition of the discarded catch

Biomass of discards were calculated and standardized per square kilometer trawled. Multivariate analyses were performed using the package *vegan* in R software (R, 2013). Species biomass was used to calculate the Bray-Curtis similarity index between hauls. Data were square-root transformed prior to analysis in order to reduce the effect of extreme values. The similarities in species composition were explored by a multidimensional ordination plot (nMDS). Differences in the species composition were tested by the function *adonis* in R package *vegan*. The three factors considered were: season, zone, and depth, with depth as a fixed factor nested in zones. Pairwise comparisons between seasons, zones, and depths were also tested using the function *adonis* by subsetting the pair of factors to compare, where the function *p.adjust* was applied in order to correct the p-value of multiple comparisons. A similarity percentage analysis (SIMPER) was used to detect the species accounting for significant differences between depths.

2.4. Discards by length

Commercial species may be regulated by the MCRS. Thus, a ratio of discarded biomass of individuals below the MCRS was calculated. Moreover, to elucidate the relationship between target species and their presence in the discard fraction of the catch, discard probability was estimated for 6 species with economic importance and MCRS regulation in the Catalan market. The species were the European hake (*Merluccius merluccius*), the red mullet (*Mullus barbatus*), the black-bellied angler (*Lophius budegassa*), the poor cod (*Trisopterus capelanus*), the deep-water pink shrimp (*Parapenaeus longirostris*) and the Norway lobster (*Nephrops norvegicus*). The discards probabilities were estimated using a standard logistic curve:

$$P(L) = \frac{e^{a+b*L}}{1 + e^{a+b*L}}$$

where P is the probability that an individual caught at a certain length (L) will be discarded. The logistic parameters (a, intercept; b, slope) were estimated using a mixed-effect logistic model. These models consider both within and between haul variability, avoiding spurious statistical significance. In order to fit the mixed-effect logistic model, the *glmer* function in the *lme4* R package was used. The effect of zone and season in the logistic curves were tested, depth was not included in the analysis because size distribution of species varied in the different depths sampled. The length at which 50% of individuals were discarded L_{50d} (defined as discarded size) (Machias et al., 2004) and the Discarded Range size (DR), term adapted from gear selectivity studies (Wileman et al., 1996), were calculated using the following equations:

$$L_{50d} = -\frac{a}{b}$$

$$DR = L_{75d} - L_{25d} \quad = -\frac{2 * \ln}{b} \tag{3}$$

where L_{75d} and L_{25d} are the lengths at which 75% and 25% of individuals were discarded, respectively.

2.5. Results

2.5.1. Discards analysis

The mean discard ratio for the Catalan trawl fishery was 25.5 ± 17.21%, with the gross estimation of yearly discarded biomass being 2685.8 ± 1813.5 t. Both the landed and discarded catch had minimum values on the lower slope (110.7 and 18.5 kg km^{-2} respectively), and maximum values on the shelf (837.4 and 641.4 kg km^{-2} respectively) (Supplementary Table S2). Average discard ratios per depth, zone, and season are shown in Supplementary Table S2.

The estimation of the model showed that discard ratios were significantly different among depths ($p < 0.001$) in each zone (Table 2a). The highest discards ratio was observed in the shallow shelf and in the shelf, both with a median of 30.5%. The shallow shelf had a significantly higher ratio than that of the lower slope, whose median was 14.3% ($p \leq 0.01$) (Fig. 2a; Supplementary Table S3a). Similarly, the shelf had a significantly higher ratio than that from the lower slope. In detail, the lower slope south coast zone ($p \leq 0.02$) (Fig. 2a; Supplementary Table S3a) had a significant effect on the discard ratio ($p < 0.001$) (Table 2a), with a higher discard ratio in the Ebre delta (30.7%) compared to the north (24.0%) and south (15.5%) coasts ($p = 0.02$ and $p < 0.001$, respectively) (Fig. 2b; Supplementary Table S3a). Model estimations showed no significant differences between discard ratios for the north and south coasts ($p \geq 0.31$; Supplementary Table S3a). Regarding seasons, no significant effect was observed among them ($p = 0.79$; Table 2a), with discard ratios ranging between 21.1% and 27.0% (Fig. 2c).

The model estimation with discarded biomass as a response variable showed significant differences among depths in each zone ($p < 0.001$; Table 2b). The highest discarded biomass was obtained in the shelf (median 147.0 kg km^{-2}) and the lowest in the lower slope (median 23.6 kg km^{-2}) (Fig. 2d). The most relevant significant differences found were observed among the shelf and the lower slope for all zones (p values ranging from 0.05 to < 0.001) and between the shelf and upper slope in the south coast (< 0.001; Supplementary Table S3b). The model estimation showed no significant differences between zones or seasons

Table 2
Statistical results of the generalized linear models (glm) applied to (a) discard ratios, (b) discarded biomass and (c) the number of species discarded across seasons, zones, and depths nested to zones.

a) Model: glm (Discards ratio ~ seasons + zone + zone/depths, family= quasipoisson)					
Deviance Explained: 18.09%					
	Df	Deviance	Resid. Df	Resid. Dev.	p-value
NULL			212	24.31	
Seasons	3	0.11	209	24.20	0.79
Zones	2	1.72	207	22.49	< 0.01
Zones:depths	5	2.57	202	19.91	< 0.01
b) Model: glm (Discarded biomass ~ seasons + zone + zone/depths, family= quasipoisson)					
Deviance Explained: 34.30%					
	Df	Deviance	Resid. Df	Resid. Dev.	p-value
NULL			212	46671	
Seasons	3	1522.40	209	45149	0.06
Zones	2	1059.10	207	44090	0.08
Zones:depths	5	13435.70	202	30654	< 0.01
c) Model: glm (Number of species discarded ~ seasons + zone + zone/depths, family= quasipoisson)					
Deviance Explained: 35.70%					
	Df	Deviance	Resid. Df	Resid. Dev.	p-value
NULL			212	1098.58	
Seasons	3	30.03	209	1068.56	0.03
Zones	2	47.50	207	1021.06	< 0.01
Zones:depths	5	315.16	202	705.91	< 0.01

($p = 0.08$ and $p = 0.06$, respectively) (Table 2b). For zones the median discarded biomass varied between 41.5 and 114.8 kg km^{-2} (Fig. 2e), and for seasons it was between 44.9 and 103.5 kg km^{-2} (Fig. 2f).

The model estimation with the number of species discarded as a response variable showed significant differences among depths in each zone ($p < 0.001$), zones ($p < 0.001$), and seasons ($p = 0.03$) (Table 2c). The highest number of species discarded was observed in the shelf (median 39 species) and the lowest in the lower slope (median 20 species) (Fig. 2g). The number of species discarded was significantly different among the lower slope and all other depths ($p \leq 0.003$; Supplementary Table S3c). Ebre delta was the zone with the highest number of species discarded (38 species) (Fig. 2h). Significant differences in the number of species discarded were observed between the north coast and both the Ebre delta ($p < 0.001$) and the south coast ($p = 0.02$; Supplementary Table S3c). Regarding seasons, spring had the highest number of species discarded, with 39 species (Fig. 2i). This value is significantly higher from summer and fall ($p = 0.04$ and $p = 0.05$, respectively) but no other differences among seasons were observed (Supplementary Table S3c).

2.6. Species composition of the discarded catch

In this study, a total of 434 species were found in the discards during sampling. A list of the most common species caught at each depth is detailed in Supplementary Table S4.

Fig. 3 plots the similarities in species composition of the discarded catches through a multidimensional ordination plot (MDS). Significant differences were found in the species composition of the discards among depths, zones, and seasons. The pairwise comparison highlighted significant differences among all depths ($p < 0.001$). A detailed table with the top species contributing to the differences in the species composition of the discarded catches in each studied depth can be found in Table 3a. The species *Scyliorhinus canicula* was a common driver accounting for differences at all depths.

Spatial variability on the species composition was also observed within zones, i.e. shelf and upper slope (Table 3b). Within the shelf, the north and the south shelves were significantly different ($p = 0.01$) and both were different from the shelf in the Ebre delta ($p = 0.001$ in both

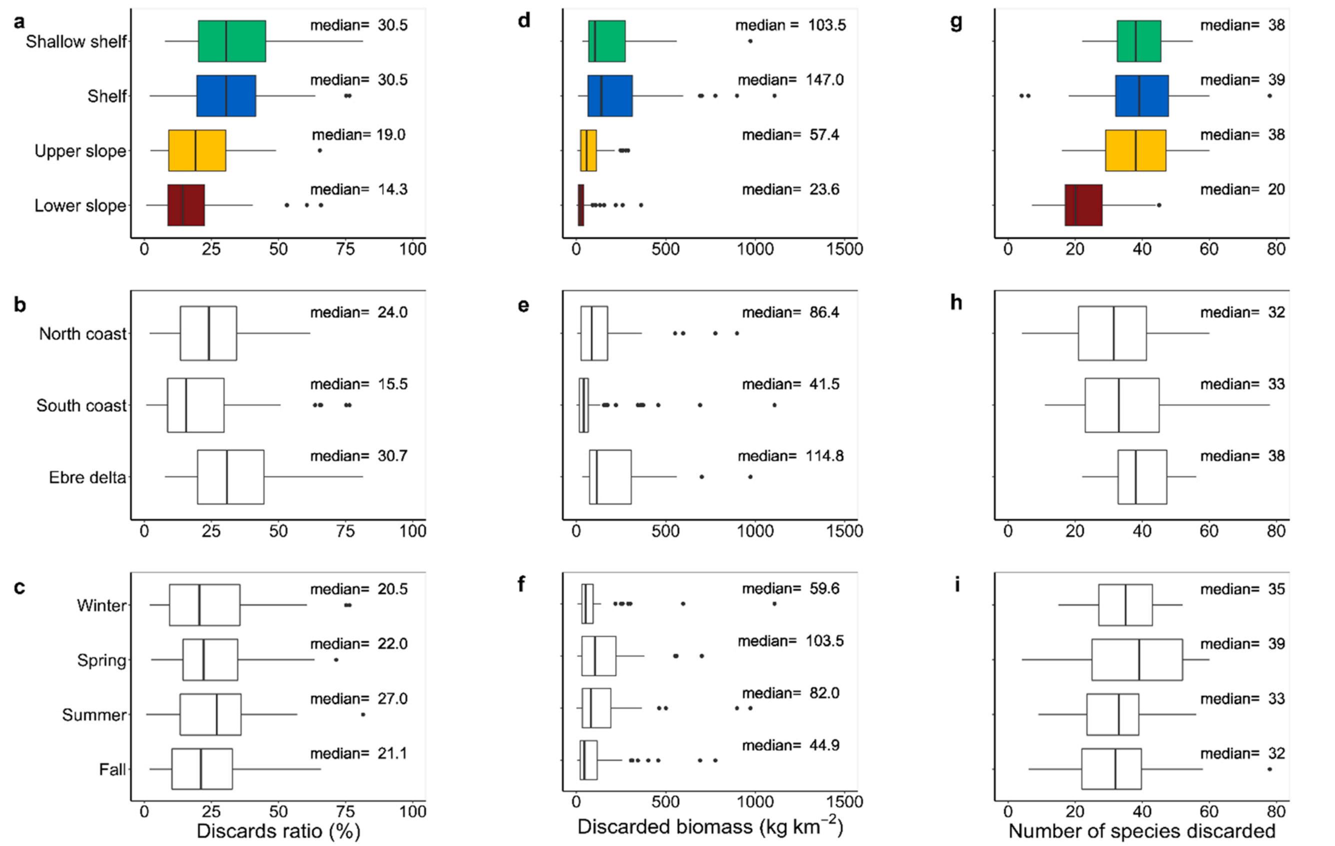

Fig. 2. Boxplot graphs showing (a) discard ratios at each depth, (b) discard ratios for each zone, (c) discard ratios for each season, (d) discarded biomass at each depth, (e) discarded biomass for each zone, (f) discarded biomass for each season, (g) number of species discarded at each depth, (h) number of species discarded in each zone, (i) number of species discarded in each season.

cases). The top species accounting for the differences in spatial variability within the shelf were as follows: i) between the north and the south shelf, the species *Trachurus trachurus*, *Echinus melo*, *Alcyonium palmatum*, and *L. budegassa*, were more abundant in the north, and *S. canicula*, *Boops boops*, *Spicara flexuosa*, *M. merluccius* and *Leptometra phalangium*, more in the south coast, accounting for 64% of the total differences; ii) between the north coast and the Ebre delta the species *S. canicula* and *T. trachurus*, were more abundant in the north coast, and *B. boops*, *Engraulis encrasicolus*, *Astropecten irregularis*, *Liocarcinus depurator*, and *M. merluccius*, were more abundant in the Ebre delta shelf, accounting for 55% of the total differences; iii) between the south coast and the Ebre delta, the species *S. canicula*, *T. trachurus*, *S. flexuosa*, *M. merluccius*, and *L. phalangium*, were more abundant in the south shelf, and *B. boops*, *E. encrasicolus*, *A. irregularis*, and *L. depurator*, more in the Ebre delta, accounting for 64% of the total differences. Within the upper slope, the north zone was significantly different from the south ($p = 0.009$). The top species accounting for these differences in spatial variability within the upper slope were *S. canicula*, *Octopus salutii*, *Conger conger*, *Lepidorhombus boscii*, and *Coelorinchus caelorhincus*, as they were more abundant in the northern upper slope, and *Galeus melastomus*, *Gadiculus argenteus*, and *Phycis blennoides*, as they were more abundant in the southern upper slope, accounting for 67% of the total differences.

Seasonal differences in the discard species composition within each depth were only observed in the shallow shelf and in the lower slope (Table 3c). In particular, in the shallow shelf there were differences between spring and fall ($p = 0.018$), the top species contributing to these differences were *B. boops*, *E. encrasicolus*, *Sardinella aurita*, and *Sardina pilchardus* which were more abundant in spring and *Trachurus mediterraneus* and *A. irregularis* which were more abundant in fall, these species accounted for 63% of the total differences. Between spring and winter ($p = 0.032$), the species were *E. encrasicolus*, *B. boops*, *S. aurita*, and *Diplodus annularis* were more abundant in spring and *T. mediterraneus* and *Squilla mantis* were more abundant in winter, these species accounted for 71% of the total differences. Between summer and fall ($p = 0.01$), the species *S. aurita*, *E. encrasicolus*, *S. pilchardus*, *Pagellus acarne*, and *L. depurator* were more abundant in summer and *T. mediterraneus* and *B. boops* were more abundant in fall, these species accounted for 58% of the total differences. In the lower slope, there were differences between spring and summer ($p = 0.015$), the top species contributing to these differences were *S. canicula*, *Galeus melastomus*, *Lampanyctus crocodilus*, *Histioteuthis bonnellii*, *Histioteuthis reversa*, and *Etmopterus spinax* which were more abundant in spring and *Hoplostetus mediterraneus* which was more abundant in summer, these species accounted for 65% of the total differences. Between spring and fall ($p = 0.007$) the species *G. melastomus*, *S. canicula*, *L. crocodilus*, and *H. bonnellii* were more abundant in spring and *Trachyrhyncus scabrus* was more abundant in fall, these species accounted for 60% of the total differences. Between summer and winter ($p = 0.019$), the species were *H. reversa*, *H. bonnellii*, and *H. mediterraneus* were more abundant in summer and *G. melastomus*, *S. canicula*, *T. scabrus*, and *L. crocodilus* were more abundant in winter, these species accounted for 61% of the total differences (Table 3c).

2.7. Discards by length

The mean ratio of discarded biomass of individuals below the MCRS considering all discards was $6.47 \pm 0.89\%$. Using this value, along with the yearly discarded biomass for the Catalan trawl fishery (2685.8 ± 1813.5 t), the yearly mean of discarded biomass of the individuals below the MCRS was 173.89 ± 16.22 t. The logistic function indicating the discard probability of the target species analyzed, *M. merluccius*, *M. barbatus*, *L. budegassa*, *T. capelanus*, *P. longirostris*, and *N. norvegicus*, is

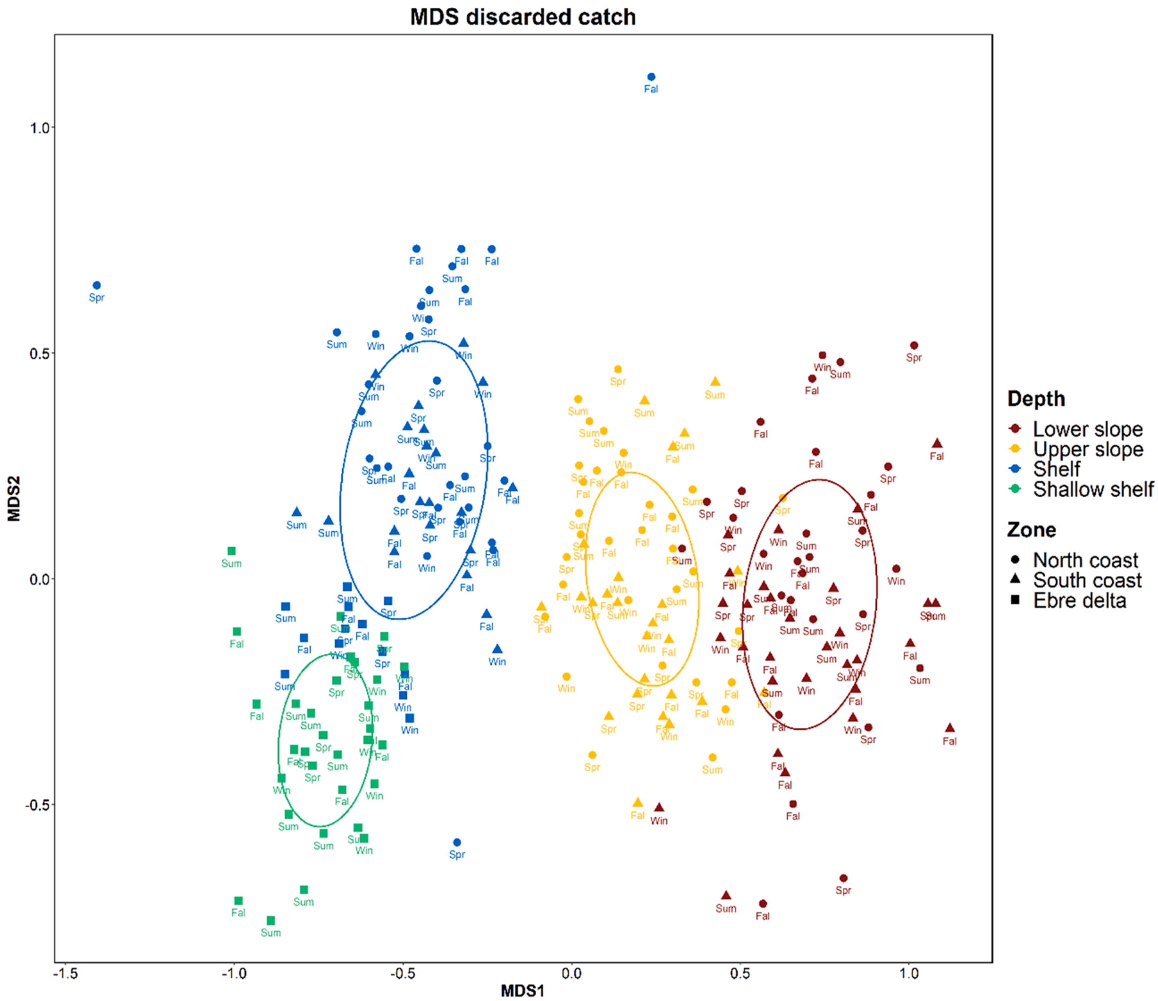

Fig. 3. Multidimensional ordination plot (MDS) of the single hauls. The different depths sampled were represented by colors (red; lower slope, yellow; upper slope, blue; shelf and green; shallow shelf). Different shapes indicate the zones sampled (circles; North coast, triangles; South coast and squares; Ebre delta). Seasons were indicated by letters (Win; winter; Spr; spring, Fal; fall and Sum; summer). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

shown in Fig. 4. There were no significant differences in the logistic curves obtained between seasons or zones. For all species, the estimated L_{50d} values were lower than the MCRS. Similarly, all species presented a L_{50d} lower than the LFM (Fig. 4). The discarded range size (DR) varied between species, with *N. norvegicus* having the highest value (DR = 3.8 ± 0.114 mm CL) (Fig. 4f) and *M. barbatus* having the lowest (DR of 0.51 ± 2.48 cm TL) (Fig. 4b).

3. Discussion

The average discard ratio observed in this study for the Catalan trawl fishery was 25.5% accounting for 2685.8 t, which falls in the lower end of values reported in other studies from the Mediterranean Sea, i.e. 20–43.3% (Gorelli et al., 2016; Sánchez et al., 2004; Tiralongo et al., 2021). Discard ratios varied greatly among depths, decreasing from shallow to deep fishing grounds, in agreement with previously reported data for trawling targeting shrimp, where increasing depths (> 400 m) generate fewer discards than shallow trawling targeting mid-water depths (Pinello et al., 2018). Some important findings from this study are the high number of species identified in the discards, up to 434, including a first citation of the fish *Polymetme corythaeola* in the Mediterranean Sea (Lombarte et al., 2021). Moreover, despite the number of individuals below the MCRS in the discards being low (6.47% and 173.89 t), the length at which 50% of the studied commercial species individuals were discarded (L_{50d}) was below the LFM and the MCRS. These main results evidence the high biodiversity that the Mediterranean Sea has to offer but, at the same time, the low specificity of trawling which generates discards including undersized commercial species, affecting the stocks sustainability.

The Mediterranean Sea has a wide variety of ecosystems and species, a fact that is mirrored in the large number of species that constitute the discards, most of them lacking of commercial value. The 434 species found is a higher amount than was found by Sánchez et al. (2004), which accounted for 309 species. This difference may be caused by the larger latitudinal gradient analyzed in the present study, including more diverse ecosystems such as the Ebre delta, a unique area with freshwater inputs from the Ebre river, which together with strong and predominant north-westerly winds and a relatively wide shelf (Salat et al., 2002) enhance species richness. The Mediterranean marine ecosystems are clearly influenced by environmental and biological factors, which are key elements to explain the differences found among depths and seasons. Depth has been found the main factor structuring megafaunal assemblages in the NW Mediterranean Sea (Papiol et al., 2012). For example, a study comparing two basins reported that as depth increased, stronger segregation occurred between the trophic groups thus different species formed each community (Valls et al., 2014). Moreover, geomorphological characteristics, bottom substratum, and depth showed direct influences on fish species assemblages (Demestre et al.,

Table 3
List of species contributing to the differences in the composition of the discarded catch among (a) different depths, (b) different zones within a same depth and (c) different seasons within a same depth.

a)

Depths compared		Species accounting for differences			
Depth 1	Depth 2	Spp 1	Spp 2	% Difference	Adonis p-value
Shallow shelf	Shelf	*Engraulis encrasicolus* *Sardinella aurita* *Sardina pilchardus*	*Boops boops* *Scyliorhinus canicula* *Trachurus trachurus*	47%	0.001
Shelf	Upper slope	*Boops boops* *Trachurus trachurus* *Spicara flexuosa* *Merluccius merluccius*	*Scyliorhinus canicula*	48%	0.001
Upper slope	Lower slope	*Scyliorhinus canicula* *Conger conger*	*Galeus melastomus* *Lampanyctus crocodilus* *Trachyrhyncus scabrus*	53%	0.001

b

Depths & zones compared		Species accounting for differences			
Depth & zone 1	Depth & zone 2	Spp 1	Spp 2	Difference	Adonis p-value
Shelf North	Shelf South	*Trachurus trachurus* *Echinus melo* *Alcyonium palmatum* *Lophius budegassa*	*Scyliorhinus canicula* *Boops boops* *Spicara flexuosa* *Merluccius merluccius* *Leptometra phalangium*	64%	0.010
Shelf North	Shelf Ebre Delta	*Scyliorhinus canicula* *Trachurus trachurus*	*Boops boops* *Engraulis encrasicolus* *Astropecten irregularis* *Liocarcinus depurator* *Merluccius merluccius*	55%	0.001
Shelf South	Shelf Ebre Delta	*Scyliorhinus canicula* *Trachurus trachurus* *Spicara flexuosa* *Merluccius merluccius* *Leptometra phalangium*	*Boops boops* *Engraulis encrasicolus* *Astropecten irregularis* *Liocarcinus depurator*	64%	0.001
Upper slope North	Upper slope South	*Scyliorhinus canicula* *Octopus salutii* *Conger conger* *Lepidorhombus boscii* *Coelorinchus caelorhincus*	*Galeus melastomus* *Gadiculus argenteus* *Phycis blennoides*	67%	0.009

c)

Depth & season compared			Species accounting for differences			
Depth	season 1	season 2	Spp 1	Spp 2	Difference	Adonis p-value
Shallow shelf	Spring	Fall	*Boops boops* *Engraulis encrasicolus* *Sardinella aurita* *Sardina pilchardus*	*Trachurus mediterraneus* *Astropecten irregularis*	63%	0.018
	Spring	Winter	*Engraulis encrasicolus* *Boops boops* *Sardinella aurita* *Diplodus annularis*	*Trachurus mediterraneus* *Squilla mantis*	71%	0.032
	Summer	Fall	*Sardinella aurita* *Engraulis encrasicolus* *Sardina pilchardus* *Pagellus acarne* *Liocarcinus depurator*	*Trachurus mediterraneus* *Boops boops*	58%	0.010
Lower slope	Spring	Summer	*Scyliorhinus canicula* *Galeus melastomus* *Lampanyctus crocodilus* *Histioteuthis bonnellii* *Histioteuthis reversa* *Etmopterus spinax*	*Hoplostetus mediterraneus*	65%	0.015
	Spring	Fall	*Galeus melastomus* *Scyliorhinus canicula* *Lampanyctus crocodilus* *Histioteuthis bonnellii*	*Trachyrhyncus scabrus*	60%	0.007
	Summer	Winter	*Histioteuthis reversa* *Histioteuthis bonnellii* *Hoplostetus mediterraneus*	*Galeus melastomus* *Scyliorhinus canicula* *Trachyrhyncus scabrus* *Lampanyctus crocodilus*	61%	0.019

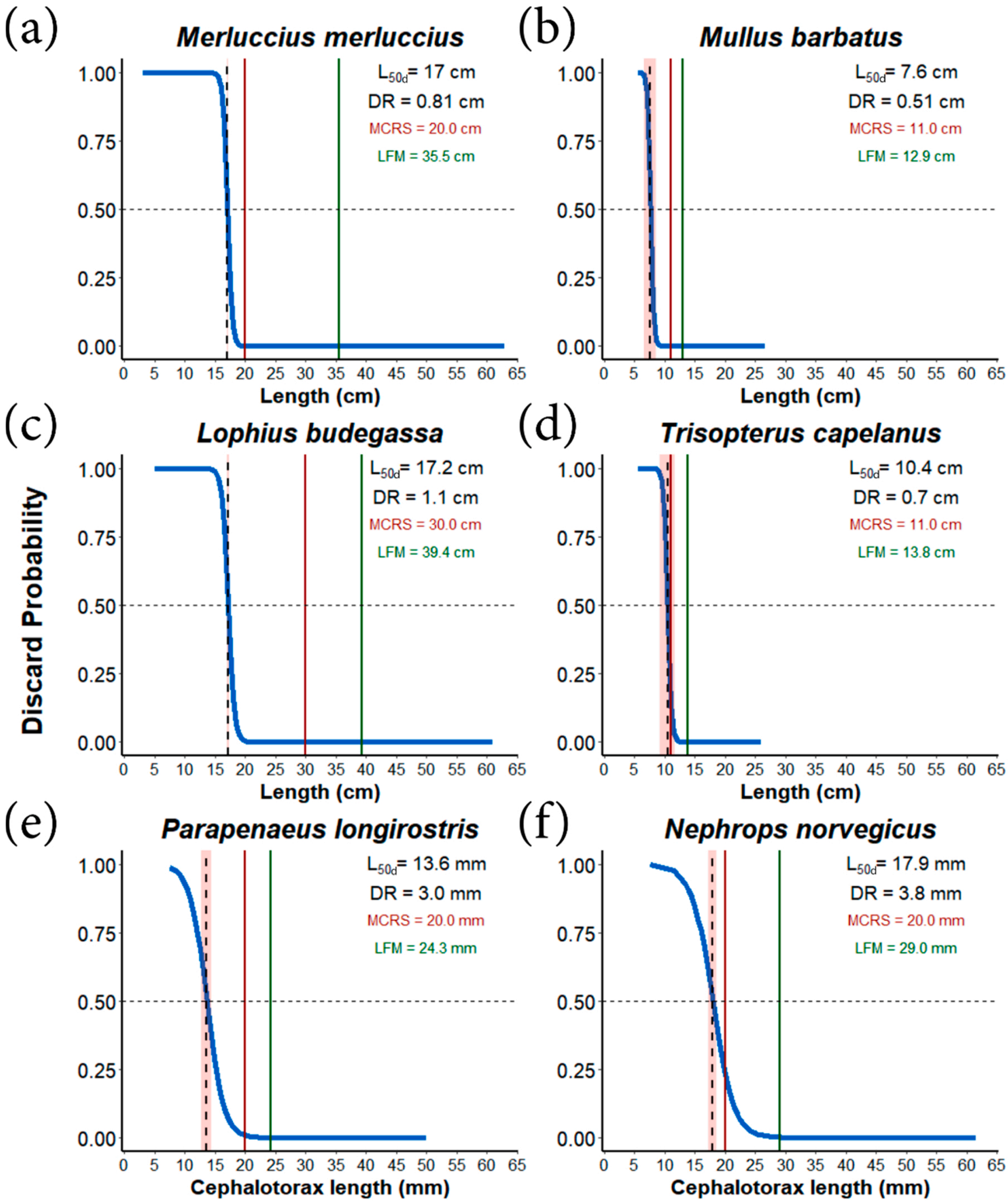

Fig. 4. Discard probability vs length based on logistic regression models for selected species of commercial interest. Black vertical dashed line indicates L_{50d} (length at which 50% of individuals were discarded, defined as discarded size) and the red blurred rectangle indicates the standard error for L_{50d}. Black dashed horizontal line indicates 50% discard probability. Red vertical line indicates MCRS (Minimum Conservation Reference Size) and the green vertical line the LFM (Length at Fist Maturity). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2000; Farré et al., 2016). In the NW Mediterranean, a study reported that different crustacean communities of decapods studied from 141 to 730 m depth were located in different depths and that the upper and middle-slope communities displayed seasonal changes in the composition and abundance of the megabenthos (Cartes et al., 1994). In accordance, other examples also report how environmental or biological factors may explain seasonality. For example, in the Ebre delta, anchovy (*E. encrasicolus*) and sardine (*S. pilchardus*) display seasonal trends depending on freshwater inputs and wind mixing events (Lloret et al., 2004). In the lower slope, differences between seasons can be explained by the presence of myctophidae species, i.e. the jewel lanternfish (*L. crocodilus*), which is more abundant in spring coinciding with an abundance of their preys (Fanelli et al., 2014). At that same depth, the cephalopod *H. reversa* was more abundant during spring and summer, probably explained due to its recruitment which takes place during spring (Quetglas et al., 2010). The presence of some species in the discarded fraction of the trawl catch may also be influenced by the fishers. This is the case of the elasmobranch *S. canicula*, a by-catch species that may be commercialized, or not, depending on the personal consideration of each fisher (Barragán-Méndez et al., 2019; Carbonell et al., 2003).

The diversity of ecosystems, resources, and stakeholders involved in

Mediterranean fisheries is challenging when designing best fisheries management practices. A pioneer study from the 60′ in the GSA 6, the "Plan Castellón", demonstrated that effective management can only be achieved if fishers, scientists, and authorities work together (Lostado et al., 1999). However, the current different regulatory measures to improve the long-term viability of fisheries, including the concept of regionalization and multi-annual plans (EU Reg. 1380/2013), do not seem to be effective (Colloca et al., 2017; Maynou, 2021). Bottom trawlers in the Mediterranean, as found in this study, catch immature individuals for most species, individuals under the MCRS, and from these species, the specimens may be captured below their length at first maturity (LFM) (Lucchetti et al., 2021). The current data then, evidences the lack of effectivity in fisheries management practices and highlights the urge to implement different management strategies to achieve sustainability, i.e. an ecosystem approach to fisheries management (EAFM). This approach is a more effective and holistic management strategy which aims to reverse the order of management priorities to start with the ecosystem rather than the target species (Pikitch et al., 2004). The study of discards, then, provide a great understanding of the exploited ecosystem and thus can be used as a guide to implement EAFM. Other evidence from the study of discards is the lack of selectivity by the fishing gear. Improving fishing gear selectivity along with other complementary measures, for example, protection of spawning and nursery grounds, spatio-temporal closures, real-time spatial closures, or changes in the spatio-temporal exploitation pattern could help fishers to increase their productivity in a more sustainable way. Increasing size and species selectivity would require considerably larger meshes, which may significantly reduce profitability (Lucchetti et al., 2021). However, despite the expected losses in economic profits in the short term, a lower but more selective catch may lead to a lower number of better paid jobs with increased stock size and constant fishing effort (Colloca et al., 2013; Maynou et al., 2021). Therefore, the adoption of more selective trawl nets could help contribute to promote ecosystem health by reducing the discards fraction, rebuilding stocks, and producing higher revenues, as well as increased labor remuneration (Colloca et al., 2013; Maynou et al., 2021; Prellezo et al., 2017) enhancing Blue Growth economies.

In conclusion, the results highlight the lack of effective local management strategies as the ecosystems from the GSA 6 are overexploited despite imposed fishing regulations (Colloca et al., 2017). Thus, the urgent need to mitigate the biological impacts of bottom trawling in the Mediterranean should be addressed by promoting the adoption of more ecologically sustainable fishing gears through the introduction of more selective meshes or of gear modifications (Lucchetti et al., 2021). The current management system is still biologically-centered instead of having an ecosystem-based approach. Thus, new strategies need cooperative and multilevel management which should not ignore the social and cultural aspects that are embedded in the fishing activity and underpin its economic performance to enhance Blue Growth (Berkes, 2012; Gómez and Maynou, 2020).

CRediT authorship contribution statement

Marta Blanco: Data curation, Investigation, Formal analysis, Writing – original draft. **David Nos:** Data curation, Investigation, Writing - review & editing. **Antoni Lombarte:** Supervision, Project administration, Conceptualization. **Laura Recasens:** Project administration, Funding acquisition. **Joan B. Company:** Conceptualization, Project administration, Funding acquisition. **Eve Galimany:** Conceptualization, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2022.106552.

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