Mediterranean Marine Science

Vol 22, No 3 (2021)

VOL 22, No 3 (2021)

Commercial catches and discards composition in the central Tyrrhenian Sea: a multispecies quantitative and qualitative analysis from shallow and deep bottom trawling

FRANCESCO TIRALONGO, EMANUELE MANCINI, DANIELE VENTURA, STEPHANIE DE MALERBE, FRANCESCO PALADINI DE MENDOZA, MASSIMILIANO SARDONE, ROBERTO ARCIPRETE, DANIELA MASSI, MARCO MARCELLI, FABIO FIORENTINO, ROBERTO MINERVINI

doi: [10.12681/mms.25753](https://doi.org/10.12681/mms.25753)

To cite this article:

TIRALONGO, F., MANCINI, E., VENTURA, D., DE MALERBE, S., PALADINI DE MENDOZA, F., SARDONE, M., ARCIPRETE, R., MASSI, D., MARCELLI, M., FIORENTINO, F., & MINERVINI, R. (2021). Commercial catches and discards composition in the central Tyrrhenian Sea: a multispecies quantitative and qualitative analysis from shallow and deep bottom trawling. *Mediterranean Marine Science*, *22*(3), 521–531. https://doi.org/10.12681/mms.25753

Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available on line at http://www.medit-mar-sc.net
DOI: http://dx.doi.org/10.12681/mms.25753

Commercial catches and discards composition in the central Tyrrhenian Sea: a multispecies quantitative and qualitative analysis from shallow and deep bottom trawling

Francesco TIRALONGO[1,2], Emanuele MANCINI[3], Daniele VENTURA[4], Stephanie DE MALHERBE[3], Francesco PALADINI DE MENDOZA[3], Massimiliano SARDONE[5], Roberto ARCIPRETE[5], Daniela MASSI[6], Marco MARCELLI[3], Fabio FIORENTINO[6] and Roberto MINERVINI[3]

[1] Department of Biological, Geological and Environmental Sciences, University of Catania, Catania, Italy
[2] Ente Fauna Marina Mediterranea, Scientific Organization for Research and Conservation of Marine Biodiversity, Avola, Italy
[3] Laboratory of Experimental Oceanology and Marine Ecology, University of Tuscia, Civitavecchia, Italy
[4] Department of Environmental Biology, University of Rome "La Sapienza", Rome, Italy.
[5] CO.BI – Biological Cooperative of Civitavecchia, Civitavecchia, Italy
[6] IRBIM-CNR, Institute for Marine Biological Resources and Biotechnologies, National Research Council, Mazara del Vallo, Italy

Corresponding author: francesco.tiralongo@unict.it

Contributing Editor: Konstantinos TSAGARAKIS

Received: 6 January 2021; Accepted: 19 July 2021; Published online: 10 September 2021

Abstract

In the Mediterranean Sea, the catch of bottom trawl fisheries is composed of a complex mix of fish and invertebrates with a considerable amount of discards. Seasonal composition of catches and discards of bottom trawls operating at different depths in the central Tyrrhenian Sea were investigated from October 2014 to October 2015. The mean total catch per unit effort (CPUE) ranged between 30.93±8.43 and 27.52±9.88 kg/h in shallow and deep fishing grounds, respectively. The discarded fraction of the catch was 39.9% in shallow and 43.3% in deep fishing grounds. The mean CPUE of commercial target species were similar in shallow and deep trawling (10.81+5.82 vs 8.92±3.16 kg/h). The commercial bycatch was lower in shallow (6.66±1.25 kg/h) than in deep grounds (8.24±2.91 kg/h), whilst the discards were lower in deep (10.43±5.14 kg/h) than shallow grounds (13.43±5.29 kg/h). Overall, 246 species were caught during fishing operations, out of which 209 were included in discards. The number of species recorded in shallow grounds (199 caught species with 166 discarded) was higher than that recorded in deep grounds (116 caught species with 102 discarded). Fish were the most represented taxa in the shallow discards, followed by echinoderms and crustaceans, and were the main discarded taxa in deep water. Depth was the main factor affecting both commercial catches and discards composition, whereas the season affected the CPUE of main target species only. The results confirmed that discards were higher in shallow than in deep trawling, suggesting that the latter is more efficient than the former in catching fishery resources for human consumption. Understanding the factors that affect discarding is the starting point for adopting management measures to mitigate negative impacts of trawl fisheries on marine resources and benthic communities.

Keywords: Western Mediterranean Sea; multi-species fishery; bycatch; unwanted catches; discarding behavior; benthic communities.

Introduction

In recent decades, discards have been considered the main problem in fisheries management all over the world (Kelleher, 2005; Roda *et al*., 2019) and measures have been adopted worldwide to mitigate this problem. The reduction of discards is one of the pillars of the reformed Common Fishery Policy (CFP) of the European Union (Reg. UE No 1380/2013). In particular, the CFP at art. 15 imposes a landing obligation for species with catch limits or, in the case of the Mediterranean, with a Minimum Conservation Reference Size (MCRS) as defined by the Reg. EC No. 1967/2006. Mediterranean bottom trawl fishery catches are characterized by a large number of species, most of which are discarded. According to Tsagarakis *et al*. (2014), discarding in Mediterranean fisheries is highly variable, with bottom trawling being responsible for the largest share of discards. The same authors reported discard rates for bottom trawling ranging from 9.6 to 64.5% of total catches. Factors affecting discards depend on species and size composition of catch, fishing patterns and gears, rules and regulations in force and market demands (Rochet & Trenkel, 2005; Tsagarakis *et al*., 2014; Tiralongo *et al*., 2018). Given the great variability of bottom trawling, it is important to collect information with a wide temporal and spatial coverage to evaluate the true dimension of discarding (Massutí *et al*., 2004; Rochet *et al*., 2014; Maeda *et al*., 2017; Milisenda *et al*., 2017; Despoti *et al*., 2020).

This study was aimed at providing new insights on the composition of the landed and discarded fractions of the catch from bottom trawlers based in Civitavecchia, Italy, one of the main fishing ports of the central Tyrrhenian Sea (western Mediterranean). In this view, the effects of depth and season on discard amount and composition from two fishing grounds were investigated: one coastal and shallow and one offshore and deep. European hake, *Merluccius merluccius* (Linnaeus, 1758), and deep water rose shrimp, *Parapenaeus longirostris* (Lucas, 1846), were the main target in both fishing grounds. Other important target species were: Red mullet, *Mullus barbatus* (Linnaeus, 1758), and hornet octopus, *Eledone cirrhosa* (Lamarck, 1798), in the shallow area; and Norway lobster, *Nephrops norvegicus* (Linnaeus, 1758), in the deeper area.

Material and Methods

Study area

The investigated area spans the Italian coast from Civitavecchia to Orbetello (central Tyrrhenian Sea; Geographical Subareas 9 of the FAO General Fishery Commission for the Mediterranean) (Fig. 1). The nature of the bottom in this area is sandy and sand-muddy, becoming muddier with increasing depth (Tortora, 1989). The margin of the continental shelf is between 120 m and 150 m depth (Chiocci & La Monica, 1996). Catch data were collected from October 2014 to October 2015. The month of October was chosen and replicated as it follows the 30 days of annual trawling closure observed in the Tyrrhenian region, which generally is from mid-September to mid-October.

The fishing fleet of Civitavecchia is composed of 14 bottom trawlers characterized by (mean values) LOA – length over all = 20.0 m; GT – gross tonnage = 46.6; engine power = 221.2 kW). The trawlers of Civitavecchia operate relatively close to the coast in an area included between the port of Civitavecchia and Orbetello. The working depth generally goes from 50 m to 500 m depth. The activity of eight trawlers was monitored in the study period. The trawlers had the same characteristics (mean LOA of 20.2±2.4 m and mean engine power of 218.3±50.86 kW) and operated along the entire area from Civitavecchia to Orbetello. Towing speed was approximately three nautical miles per hour. The fishing gear used was the so-called “volantina” bottom trawl nets, with a codend mesh sizes of 40 mm squared or 50 mm diamond and a vertical opening of 3–4 m (Sala *et al*., 2013).

Sampling and laboratory analysis

The shallow fishing grounds (“SHALLOW” hereon) cover bottoms between 50 m and 120 m depth, while the deep fishing grounds (“DEEP” hereon) spans from 240 m to 500 m depth (Fig. 1). The area between 120 and 240 m depth, covering the outer shelf and the inner slope, is not suitable for trawling. However, no fishing restrictions were in place for this area. Each monitored fishing trip started at about 3 a.m. and ended between 4 and 6 p.m. On SHALLOW fishermen performed four hauls per day, with a mean duration of about 2-hr 30 minutes per haul;

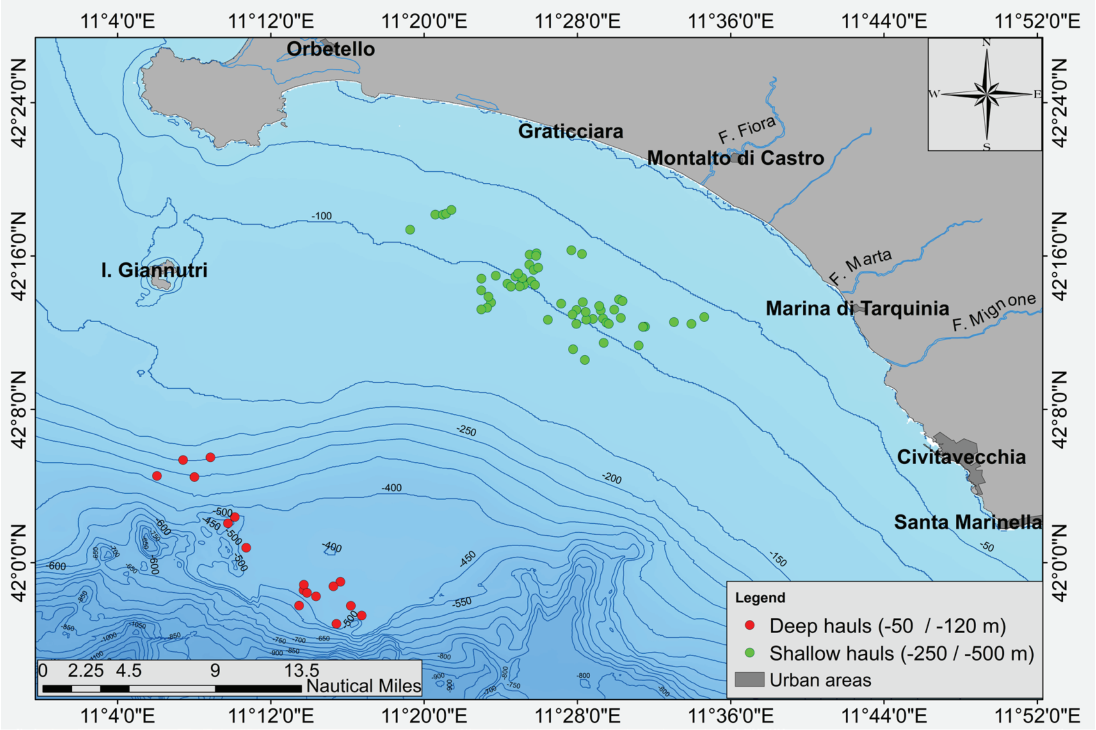

Fig. 1: Study site and locations of shallow (green points) and deep hauls (red points). Bathymetric contours are shown in blue.

on DEEP trawlers performed two hauls, with a mean duration of 5 hr per haul. Therefore, the total fishing time was about 10 hr per fishing day on both fishing grounds. Each month, two vessels were monitored in the same day.

At least two observers were boarded on each fishing trip. Sampling activity did not interfere in any way with the normal fishing activity: in particular, the sorting procedures (a subdivision of the catch into retained and discarded fractions) were performed only by fishermen, according to their usual routines. A total of 78 hauls during 24 bottom trawls trips (15 in SHALLOW and 9 in DEEP) were monitored monthly, from October 2014 to October 2015. Coordinates, depth and time of start and end points by haul were recorded. The biomass of target and commercial bycatch in kg were logged. The discarded fraction of catch was weighed and a random sample of about 10 kg was collected, stored in plastic bags and maintained at 4 °C on board. At the end of the fishing day, all the samples were brought to the laboratory and frozen. After thawing, all organisms were identified to the lower taxonomic level possible, counted and weighed to the nearest 0.1 g. The scientific name of the species was attributed according to WoRMS Editorial Board (2021).

Data analysis

According to Sartor *et al*. (2003) the sorted catch was divided in the following categories: i) target species (commercial fraction of target species); ii) commercial bycatch “the commercial fraction of the catch without the target species”; iii) discards (non-commercial species), that is all specimens caught and discarded at sea because not edible or not suitable for the market, including also undersized specimens of categories i) and ii).

Biomass data by fishing trip was processed to estimate catch per unit of effort (CPUE) in kg/hr. To assess the representativeness of species composition in the samples, accumulation curves (rarefaction method) by haul were calculated (Barberá *et al*., 2012).

The Shannon-Wiener (H’) and the Pielou’s evenness indices (J) were estimated to evaluate the species diversity and evenness in the catch (landing plus discards). H’ values can theoretically vary between 0 and $+\infty$ (the higher the biodiversity, the higher the value); while, J values can theoretically vary between 0 and 1 (the higher the value, the more evenly species are distributed).

Data were row-standardized by dividing each entry by its row total (Clarke & Warwick, 1994). Row-standardization is appropriate when large differences in species abundance can occur in the whole sample as a consequence, for example, of large differences in body-size between species (Colloca *et al*., 2003).

Trawl stations were sorted using non-metric multidimensional scaling (NMDS), based on Bray–Curtis similarity within the “metaMDS” function implemented in the “Vegan” R package (Oksanen *et al*., 2013). NMDS preserves the rank order of the inter-samples distance, as opposed to the linear relationship of classical metric scaling (i.e. principal component analysis, correspondence analysis). NMDS has the advantage of robustness being not sensitive to outliers (e.g. occurrence of one individual of large biomass in a site) and it has been widely used to analyse demersal assemblages (Ungaro *et al*., 1999, Colloca *et al*., 2003).

One-way analysis of similarities (ANOSIM) was used to test for differences between fishing areas (SHALLOW and DEEP) according to catch categories (Target, Bycatch and Discards). Species that contributed mostly to average Bray Curtis similarity between sample groups were identified using the similarity of percentages in the SIMPER routine (PRIMER v. 6.1, Clarke & Gorley, 2006).

The discard ratio (DR), defined as the ratio between the weight of discarded fraction (in weight) and the total catch (Tsagarakis *et al*., 2017), was used for comparisons with other studies.

All calculations were carried out using the R computing environment (R Development Core Team, 2019), with extensive use of the vegan library (Oksanen *et al*., 2013).

Results

A total of 246 species were recorded in catch (landing and discards) (Supplementary material, Table S1): 110 bony fish, 10 cartilaginous fish, 43 crustaceans, 34 molluscs, 23 echinoderms, 26 other Taxa (e.g. Polychaetes, Cnidaria, Tunicata). Fish accounted for almost half of the recorded species (48.8%), followed by crustaceans (17.5%), molluscs (13.8%) and echinoderms (9.5%). One hundred and thirty (130) species were sampled only in SHALLOW, while 47 species were sampled only in DEEP (Supplementary material, Table S1). It is worth noting that 69 species were common to both fishing grounds. The species accumulation curve showed that the sampled hauls gave a good description of species composition in catch (Fig. S1).

The total catch in SHALLOW amounted to 4640 kg, corresponding to a mean catch per unit effort (CPUE) over the whole investigated period of 30.93±8.43 kg/hr. Target species accounted for 35.1% of total biomass caught, while commercial by-catch and discards accounted for 21.4% and 43.4%, respectively. In DEEP, the total catch amounted to 2477.1 kg, with a mean CPUE of 27.52±9.88 kg/hr. The 32.09% of the catch was composed by target species, 29.99% by commercial by-catch and 37.92% by discard.

Considering the CPUE of different categories over the whole period, the discarded fraction resulted higher in SHALLOW than in DEEP, but the difference was not significant. Likewise, no significant differences were found between the two fishing grounds in terms of target species and commercial bycatch amount (Fig. 2).

The CPUE of target species in SHALLOW showed the highest values in autumn: 4.63± 0.98 kg/hr for *M. merluccius*, 5.85±0.74 kg/hr for *E. cirrhosa* and 5.12±0.89 kg/hr for *P. longirostris*. In the other seasons, the catch rates of the target species were much lower, with exception of *M. barbatus* that showed the highest catch rate (2.11±0.75 kg/hr)

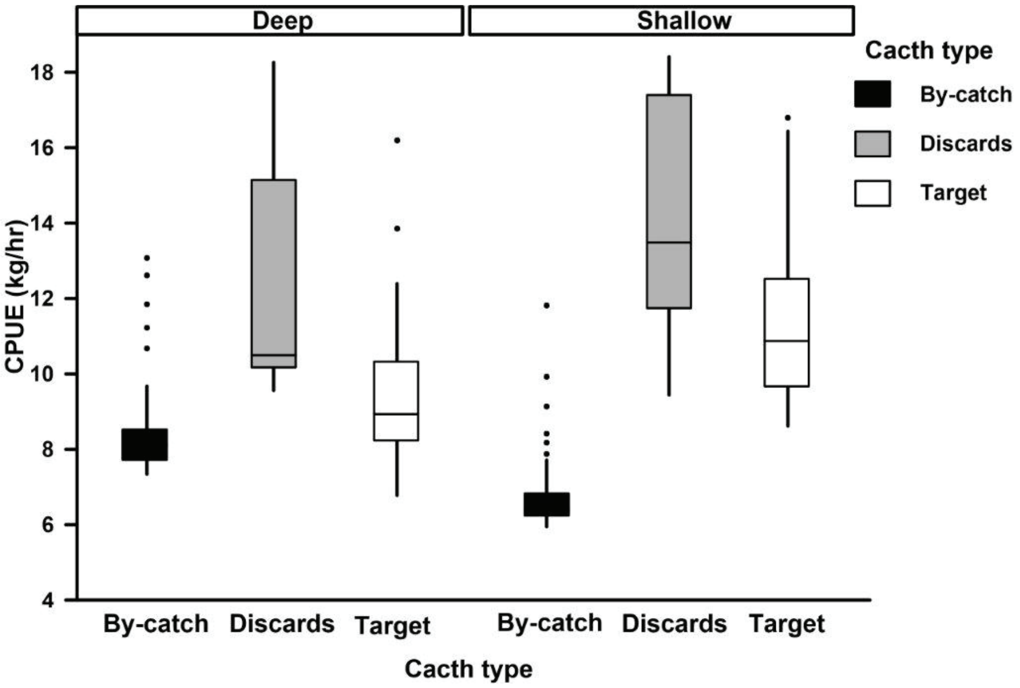

Fig. 2: CPUE estimates according to catch categories and fishing grounds.

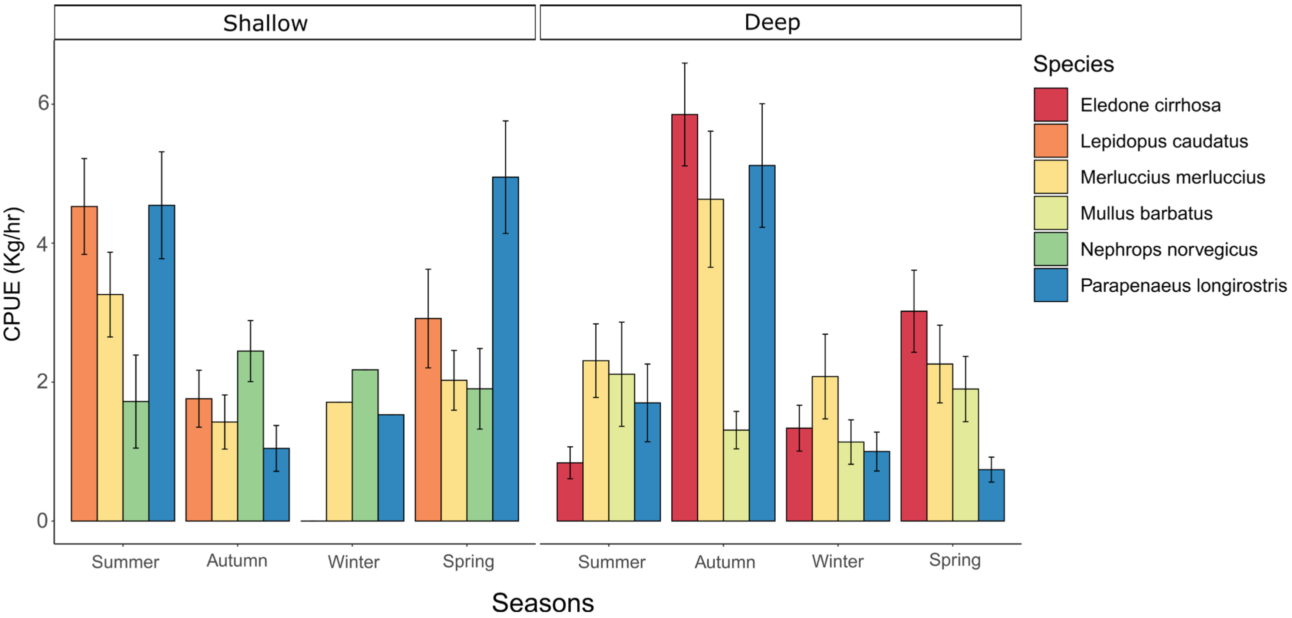

Fig. 3: Barplot showing CPUE (Kg/hr) distributions of target species by seasons and fishing grounds (DEEP and SHALLOW).

in summer (Fig. 3). The catch rates of *N. norvegicus* in DEEP peaked (2.45±0.44 kg/hr) in autumn, and gradually decreased to the minimum value (1.72±0.67 kg/hr) in summer. *Merluccius merluccius* and *M. barbatus* catch rates showed an opposite trend, with maximum values in spring and summer, respectively (Fig. 3).

The number of species in the discards per fishing day was significantly higher than the other two catch categories (Chi-squared test= 62.139, df = 5, $p < 0.0001$) (Fig. 4). The number of discarded species in SHALLOW ranged from a minimum of 26 to a maximum of 51 per haul, with a mean of 36 species. The discarded species per haul in DEEP ranged from a minimum of 15 to a maximum of 34, being the mean 26. Fish, followed by echinoderms, were the most represented taxa in the SHALLOW discards. On the contrary, in all seasons, the most important taxa in the DEEP discards were crustaceans (up to > 90 %), followed by fish (Fig. 5).

Overall, the mean ecological indices for discards, with the exception of winter (H'=2.97 and J=0.87 in DEEP vs. H'=2.57 and J=0.69 in SHALLOW), were higher in SHALLOW ($1.9 \leq H' \leq 2.5$; $0.6 \leq J \leq 0.7$) than in DEEP ($1.2 \leq H' \leq 1.9$; $0.4 \leq J \leq 0.5$), showing the lowest values in summer in both fishing grounds (Table 1). The annual mean of the indices

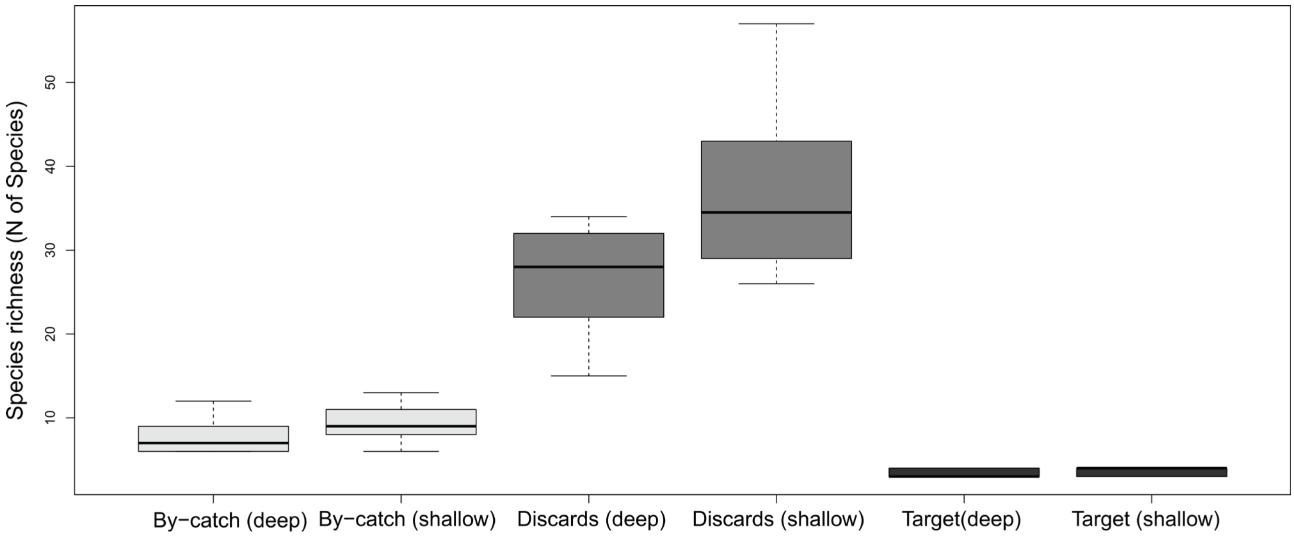

Fig. 4: Species richness according catch categories and fishing grounds.

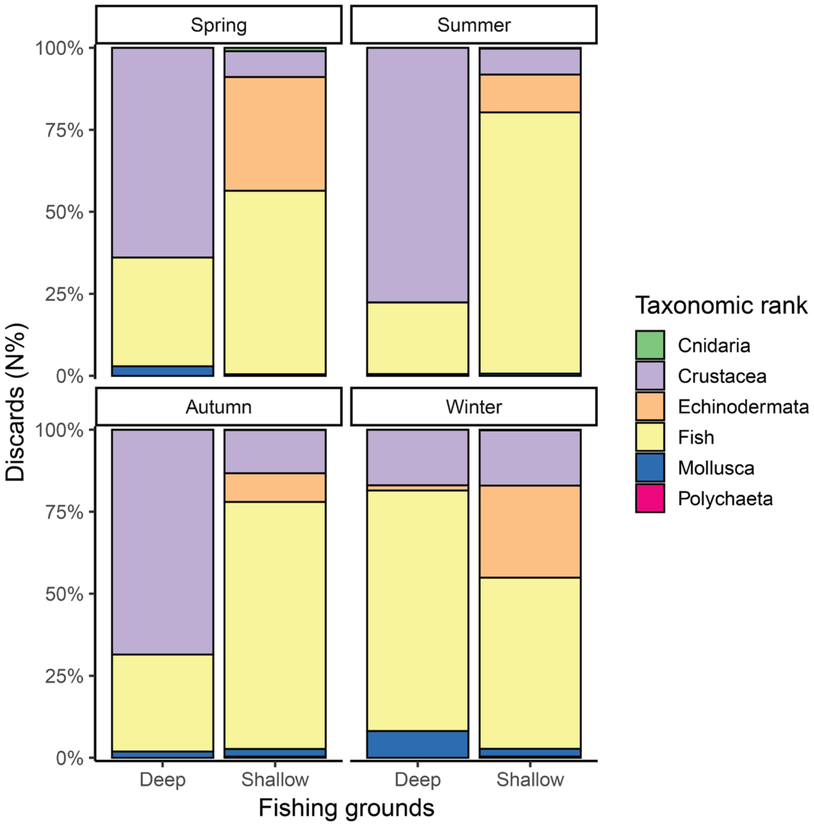

Fig. 5: Percentage in number (N%) of the main taxa in discards according to season and fishing grounds.

Table 1. Shannon diversity Index (H’) and Pielou’s evenness (J) of discard according to season and fishing grounds.

	Shallow		Deep	
	H’	**J**	**H’**	**J**
Autumn	2.51	0.68	1.82	0.55
Winter	2.57	0.69	2.97	0.87
Spring	2.40	0.71	1.92	0.55
Summer	1.93	0.57	1.18	0.40

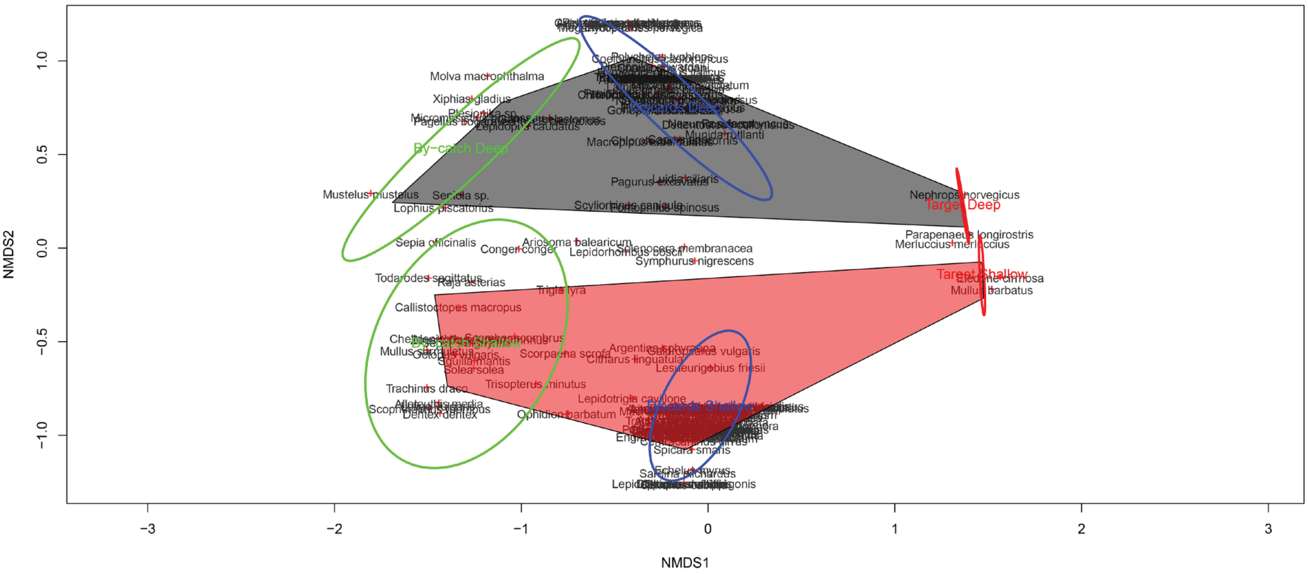

Fig. 6: NMDS ordination plot of biomass data obtained from bottom-trawl station from October 2014 to October 2015. Convex hull polygons enclosed fishing grounds which can be regarded as a proxy of depth (grey polygon = DEEP hauls from 250 and 500 m; red polygon = SHALLOW hauls form 50 and 120 m). Enclosed areas by circles are 95% confidence ellipses on the group means according catch categories (Bycatch, Discards and Target). Red cross represents most important species.

was H'=2.35±0.48 and J=0.66±0.11 for SHALLOW and H'=1.7±0.67 and J=0.52±0.18 for DEEP.

NMDS ordination plot showed a clear separation in the studied assemblages. Based on trawl species composition, two main groups, appeared structured vertically along a depth gradient. Both discards and by-catch species from shallow hauls were well separated by those found in deep hauls. Only target species such as *M. merluccius* and *P. longirostris* are close to each other because they were caught in both deep and shallow hauls (Fig. 6).

One-way ANOSIM showed significant differences in catch between fishing grounds and catch categories (Global R = 0.898, Significance = 0.001) (Table 2). SIMPER analysis showed that only 15 species contributed more than 10% to the observed similarity among the six groups identified by NMDS. Among the target species, *M. merluccius* and *P. longirostris* were confirmed to have similar importance in DEEP and SHALLOW. Results confirmed the importance of *M. barbatus* and *E. cirrhosa* in SHALLOW, while *Lepidopus caudatus* (Euphrasen, 1788) and *Phycis blennoides* (Brünnich, 1768) should be added to *N. norvegicus* in characterizing the target species in DEEP. Species characterizing by-catch were *Octopus vulgaris* Cuvier, 1797 and *Squilla mantis* (Linnaeus, 1758) in SHALLOW, while *P. blennoides* and *Lophius* spp. characterised by-catch in DEEP. Another by-catch species contributing to similarity of the two fishing grounds was the cephalopod *Todarodes sagittatus* (Lamarck, 1798). It is worth noting that discard in SHALLOW is mainly characterised by *Engraulis encrasicolus* (Linnaeus, 1758) and *Trachurus trachurus* (Linnaeus, 1758), while that of DEEP by *Galeus melastomus* Rafinesque, 1810, *P. blennoides* and *Lepidopus caudatus* (Table 2).

Overall, mean DR was higher in SHALLOW than DEEP. The lowest values were found in autumn (0.26 for SHALLOW and 0.17 for DEEP) with similar values found in winter. The discard ratio values increased gradually until summer (0.42 for SHALLOW and 0.26 for DEEP).

Discussion

Depth and its correlated factors (e.g., substrate type, hydrodynamics, light intensity, steepness) were the main drivers affecting species distribution, along with the demersal assemblages and the catch composition (Demestre *et al.*, 2000; Biagi *et al.*, 2002; Gaertner *et al.*, 2002; Colloca *et al.*, 2003; Cartes *et al.*, 2009; Busalacchi *et al.*, 2010; Soykan *et al.*, 2019).

In our study, species diversity both of commercial and discarded catch was higher in SHALLOW (199 caught species with 166 discarded) than in DEEP (116 caught species with 102 discarded). In particular, fish showed a general decrease in number of species with increasing depth, being the dominant group in SHALLOW together with echinoderms. On the contrary, crustaceans were the dominant group in DEEP. *Merluccius merluccius* and *P. longirostris* were the target species with similar importance in both DEEP and SHALLOW. *Mullus barbatus* and *E. cirrhosa* were important target species in SHALLOW, while *L. caudatus* and *P. blennoides*, together with *N. norvegicus* were important target species in DEEP. In SHALLOW, by-catch was mainly characterized by *O. vulgaris* and *S. mantis*; while in DEEP, the species characterizing by-catch were *P. blennoides* and *Lophius* spp. In SHALLOW, discards were mainly characterised by *E. encrasicolus* and *T. trachurus*, while *G. melastomus* together with *P. blennoides* and *L. caudatus* characterized discards in DEEP.

Sartor *et al.* (2003), investigating catch of deep wa-

Table 2. One-way ANOSIM and SIMPER analysis of biomass values among the six groups identified by DCA according fishing grounds and catch categories. (By = bycatch; TG = target; DI = Discards). Only contributions > 10% are reported.

ANOSIM	**SIM-PER**								
Groups	***R***	***P***	**Average similarity (%)**	BY-DEEP (43.78)	BY-SHALLOW (37.08)	TG-DEEP (84.05)	TG-SHALLOW (79.51)	DI-DEEP (46.18)	DI- SHAL-LOW (48.34)
Global	0.898	0.001							
BY-DEEP, DI-DEEP	0.853	0.002	*Eledone cirrhosa*				28.72		
BY-DEEP, TG-DEEP	0.96	0.001	*Engraulis encrasicolus*						14.3
DI-DEEP, DI-SHALLOW	0.688	0.001	*Gadiculus argenteus*	11.59					
BY-DEEP, DI-SHALLOW	1.00	0.001	*Galeus melastomus*					10.17	
BY-DEEP, TG-SHALLOW	1.00	0.001	*Lepidopus caudatus*	33.4				10.43	
DI-DEEP, TG-DEEP	0.989	0.002	*Lophius* spp.	10.95					
DI-DEEP, BY-SHALLOW	0.949	0.001	*Merluccius merluccius*			33.05	36.58		
DI-DEEP, DI-SHALLOW	0.998	0.001	*Mullus barbatus*				17.94		
DI-DEEP, TG-SHALLOW	0.993	0.001	*Nephrops norvegicus*			30.58			
TG-DEEP, BY-SHALLOW	0.966	0.001	*Octopus vulgaris*		20.52				
TG-DEEP, DI-SHALLOW	1.00	0.001	*Parapenaeus longirostris*			34.42	16.76		
TG-DEEP, TG-SHALLOW	0.92	0.001	*Phycis blennoides*	13.48				11.48	
BY-SHALLOW, DI-SHALLOW	0.878	0.001	*Squilla mantis*		18.4				
BY-SHALLOW, TG-SHALLOW	0.989	0.001	*Todarodes sagittatus*	12.84	23.37				
DI-SHALLOW, TG-SHALLOW	1.00	0.001	*Trachurus trachurus*						12.35

ter trawlers of Porto Santo Stefano (north Tyrrhenian Sea) in the second half of the 1990s targeting deep water crustaceans, reported a total of 155 taxa, of which 86 were fish, 41 crustaceans, 20 molluscs and 8 belonging to other invertebrates. Considering the shallower (300-450 m) fishing grounds, targeting *N. norvegicus* and *P. longirostris*, 86 fish (66 discarded), 41 crustaceans (35 discarded), 20 molluscs (18 discarded) and 8 belonging to other invertebrates (all discarded) were caught. Differently, in the deeper (450-650 m) fishing grounds, targeting red shrimps - *Aristeus antennatus* (Risso, 1816) and *Aristaeomorpha foliacea* (Risso, 1827), 86 fish (44 discarded), 41 crustaceans (28 discarded), 20 molluscs (11 discarded) and 3 belonging to other invertebrates (all discarded) were caught. These findings showed that the species richness, mainly in terms of discarded fraction, was higher in the upper than in the deeper slope.

Sánchez *et al*. (2004), monitoring the catch of bottom trawlers off Vilanova i la Geltrú (Catalan Sea) targeting *M. barbatus*, *M. merluccius* and *A. antennatus*, found 335 species, distributed as follow: 144 Fish (73 discarded), 64 crustaceans (40 discarded), 57 molluscs (37 discarded) and 70 other invertebrates (67 discarded). Excluding the shallowest (14-35 m) and the deepest (405-773 m) fish assemblages, the species richness, species diversity (H) and evenness (J) in depth ranges comparable with those in our study were higher in the cluster 35-78 m (2.37≤H≤=2.44; 0.60≤J≤=0.78±) than in 119-391 m (1.7≤H≤=1.85; 0.53≤J≤=0.58), in terms of both commercial and discarded fractions.

The decrease in diversity indices of discarded species, with increasing depth reported by Sartor *et al*. (2003) and Sánchez *et al*. (2004) was in line with our results, showing species higher richness, diversity and evenness in SHALLOW than in DEEP in all seasons, except for winter.

Damalas *et al*. (2018) reported that fish dominated both discards and landings of trawlers in the Ligurian and the north Tyrrhenian seas. One hundred fifty-one (151) fish species were discarded, with hake and pilchard accounting for most of the discarded species, whereas 136 fish species were landed. In addition, 36 species of crustaceans and 26 species of cephalopods were discarded. Species of commercial interest included significant quantities of crustaceans (45 species) and cephalopods (29 species), especially from fishing grounds deeper than 300m, whilst most of the other invertebrates were discarded.

Considering the western Mediterranean, a pattern related to depth was found for discard ratio, with the median of rates of 47.2% (35.0–64.5) (Sartor *et al*., 2001; Martínez-Abraín *et al*., 2002; Carbonell *et al*., 2003a; Sánchez *et al*., 2004) in shallow water trawling and of 30.0% (19.5-42.0) (Moranta *et al*., 2000; Carbonell *et al*., 2003b; Sartor *et al*., 2003; Sánchez *et al*., 2007; Gorelli *et al*., 2016;) in deep water trawling. On the other hand, Damalas *et al*. (2018), investigating discarding in the Ligurian and North Tyrrhenian seas and in the Aegean Sea, reported that, overall, the discard ratio (%) was negatively related to depth.

On the other hand, patterns arising from other areas of the Mediterranean are more variable. A positive correlation between the discarded fraction and depth was found by D'Onghia *et al*. (2003) in the Ionian Sea. On the contrary, Edelist *et al*. (2011) found a decreasing trend with increasing depth off the Israeli coast.

Despite the effects of depth are known, the relationship between the discarded fraction and depth can be modified through the operational pattern of fishing. According to Milisenda *et al*. (2017), different fishing strategies can affect the composition and amount of discards in the catch of Italian trawlers operating in the Strait of Sicily. In the case of the coastal fleet operating in the territorial waters with daily fishing trips, fishers would land species with low commercial value, while the distant fleet operating in international waters with fishing trips lasting weeks or months would land mainly species with high economic value, with a related increase of discard.

Season was found to be another factor concurring with depth to affect species distribution and abundance and, consequently, catch and discard composition (Massutí & Reñones, 2005; Sánchez *et al*., 2007; Pillai *et al*., 2014). Gücü (2012), investigating the Turkish trawlers operating in the Levant Sea, reported that both depth and month affected discard rates. In particular, in the Levant Sea, discarding decreased with increasing depth up to 100-150 m, followed by an increasing pattern up to about 250 m. On the other hand, season affected discarding, with the highest values occurring from August to October. However, recently, Damalas *et al*. (2018) could not find a significant effect of season on the amount and composition of trawl discards in the Ligurian, north Tyrrhenian and Aegean seas. A similar pattern was also recorded in our study. The catch rates of the three main target species of SHALLOW (*M. merluccius*, *P. longirostris*, and *E. cirrhosa*) were considerably higher in autumn, after the 30-day trawling ban, although, overall, no statistically significant differences were observed. This lack of significance could be due to the relatively lower number of samples taken by season. The highest CPUE in summer of *M. barbatus* could be explained by the reproductive migration to grounds around 100 m depth, occurring in most areas of the Mediterranean in spring/summer (Voliani *et al*., 1998; Fiorentino *et al*., 2008). The seasonal catch rates of the target species in DEEP showed a different pattern. *Nephrops norvegicus* (the main target species) was the only case for which yield values were greater in autumn and gradually decreased until summer. For *M. merluccius, P. longirostris* and *L. caudatus* the highest values were observed in spring/summer.

According to Sánchez *et al*. (2004), ecological efficiency, expressed as discard ratio, varied according to depth, ranging between 0.2 (119-773m) and 0.65 (14-35m). A better ecological efficiency in deep fisheries was also observed by Sartor *et al*. (2003), who reported discard ratios (DR) ranging between 0.15 and 0.25 at depths of 300-450 m and between 0.20-0.30 at depths of 450-650 m, with maxima in spring in both cases. These DR values agreed with our results (0.3-0.4 in SHALLOW, and 0.2-0.3 in DEEP), even if our lowest DR were found in autumn and winter.

The high number of samples analysed and the accuracy of taxonomical analysis performed allowed us to collect detailed data on the catch composition of the trawl fishery of Civitavecchia and draw-up an exhaustive list of the species caught in the investigated fishing grounds. On the other hand, we are aware of the limitations of the study due to the small spatial and temporal coverage of sampling. Considering this, further studies on a larger spatial and temporal scale are necessary in order to better characterize the trawl fishing activity in the central Tyrrhenian Sea and its impact on marine communities, and to draw useful results in order to better manage the biological resource of the area.

Conclusions

Literature outlined highly variable discarding patterns in Mediterranean bottom trawl fisheries (Tsagarakis *et al*., 2014; Uhlmann *et al*., 2014), however, some general features seem to be evident in fully developed bottom trawl fisheries of the western Mediterranean European countries. Our results and literature showed that trawling off the continental shelf and in shallow fishing grounds produced higher discard ratios than deep water grounds on the slope.

According to Pinello *et al*. (2018), the evolution from classic multispecies fisheries operating off the shelf grounds to a fishery targeting deep-water crustaceans on the slope could shift trawling of the Mediterranean fleets towards a more sustainable pattern from both economic and ecological point of views.

However, it is worth noting that the discard ratio (retained fraction over the total catch), which is considered as a classic measure of ecological efficiency of bottom trawling, is not sufficient to describe the impact of bottom trawl fisheries. In this respect, it is well known that bottom trawling modifies the physical structure and complexity of benthic habitat (e.g. Kaiser *et al*., 2000; Collie *et al*., 2005; Pitcher *et al*., 2016), reducing the abundance of benthic invertebrates and overall biodiversity (Lauria *et al*., 2017).

Management strategies should be identified to mitigate the impact of bottom trawling on soft bottoms. In this sense, in the Mediterranean, the closure to trawling of specific areas such as those supporting the so called Vulnerable Marine Ecosystems (Ashford *et al*., 2019) as well as Essential Fish Habitats could contribute to maintaining fishing productivity while securing biodiversity conservation. In addition, given the high discard ratios and related negative impacts of coastal trawling on shallow water marine communities (Jennings *et al*., 2001; Thrush *et al*., 2002), particular attention should be paid to coastal waters.

Acknowledgements

This study was funded by the Italian Ministry of Agriculture, Food and Forestry Policies (MiPAAF, project code 8A1). The authors are grateful to Dr. Cinzia Dante and Dr. Roberto Cherubini for the authorization to publish the results and to the fishermen of Civitavecchia for their kind collaboration and hospitality on board. This study is also indented to be a contribution to the memory of Prof. Roberto Minervini, who disappeared prematurely leaving an unbridgeable void in all of us. The authors thank the anonymous reviewers for their helpful comments and Dr. Luca Ceriola for the English language revision.

References

Ashford, O.S., Kenny, A.J., Barrio Froján, C.R., Downie, A., Horton, T. *et al.*, 2019. On the influence of Vulnerable Marine Ecosystem habitats on peracarid crustacean assemblages in the Northwest Atlantic Fisheries Organisation Regulatory Area. *Frontiers in Marine Science*, 6, 401.

Barberá, C., Moranta, J., Ordines, F., Ramón, M., De Mesa *et al.,* 2012. Biodiversity and habitat mapping of Menorca Channel (western Mediterranean): implications for conservation. *Biodiversity and conservation*, 21 (3), 701-728.

Biagi, F., Sartor, P., Ardizzone, G. D., Belcari, P., Belluscio, A. *et al.*, 2002. Analysis of demersal fish assemblages of the Tuscany and Latium coasts (north-western Mediterranean). *Scientia Marina*, 66 (S2), 233-242.

Busalacchi, B., Rinelli, P., De Domenico, F., Profeta, A., Perdichizzi, F. *et al.*, 2010. Analysis of demersal fish assemblages off the Southern Tyrrhenian Sea (central Mediterranean). *Hydrobiologia*, 654 (1), 111-124.

Carbonell, A., Alemany, F., Merella, P., Quetglas, A., Román, E., 2003a. The by-catch of sharks in the western Mediterranean (Balearic Islands) trawl fishery. *Fisheries Research*, 61 (1-3), 7-18.

Carbonell, A., Pomar, G., Gaza, M., Torres, A., García, M. *et al.,* 2003b. The deep-water red shrimp fishery in the Spanish Mediterranean Sea. *Journal of Northwest Atlantic Fishery Science*, 31.

Cartes, J.E., Maynou, F., LLoris, D., De Sola, L.G., Garcia, M., 2009. Influence of trawl type on the composition and diversity of deep benthopelagic fish and decapod assemblages off the Catalan coasts (western Mediterranean). *Scientia Marina*, 73 (4), 725-737.

Chiocci, F.L., La Monica, G. B., 1996. Analisi sismostratigrafica della piattaforma continentale. *Il Mare del Lazio*, 40-61.

Clarke, K.R., Warwick, R.M., 1994. Similarity-based testing for community pattern: the two-way layout with no replication. *Marine Biology*, 118 (1), 167-176.

Clarke, K.R., Gorley, R.N., 2006. PRIMER v6: user manual/tutorial, Primer E: Plymouth. *Plymouth Marine Laboratory, Plymouth, UK*.

Collie, J.S., Hermsen, J.M., Valentine, P.C., Almeida, F.P., 2005. Effects of fishing on gravel habitats: assessment and recovery of benthic megafauna on Georges Bank. In: *Benthic Habitats and the Effects of Fishing: Proceedings of Symposium on Effects of Fishing Activities on Benthic Habitats-Linking Geology, Biology, Socioeconomics, and Management, Held in Tampa, Florida, USA, 12-14 November 2002* (Vol. 41, pp. 325-343). American Fisheries Society.

Colloca, F., Cardinale, M., Belluscio, A., Ardizzone, G., 2003.

Pattern of distribution and diversity of demersal assemblages in the central Mediterranean Sea. *Estuarine, Coastal and Shelf Science*, 56 (3-4), 469-480.

Damalas, D., Ligas, A., Tsagarakis, K., Vassilopoulou, V., Stergiou, K.I. *et al.*, 2018. The "discard problem" in Mediterranean fisheries, in the face of the European Union landing obligation: The cases of bottom trawl fishery and implications for management. *Mediterranean Marine Science*, 19 (3), 459-476.

Demestre, M., Sanchez, P., Abello, P., 2000. Demersal fish assemblages and habitat characteristics on the continental shelf and upper slope of the north-western Mediterranean. *Journal of the Marine Biological Association of the United Kingdom*, 80 (6), 981-988.

Despoti, S., Milisenda, G., Ligas, A., Bentes, L., Maynou, F. *et al*., 2020. Marine spatial closures as a supplementary tool to reduce discards in bottom trawl fisheries: Examples from southern European waters. *Fisheries Research*, 232, 105714.

D'Onghia, G., Carlucci, R., Maiorano, P., Panza, M., 2003. Discards from deep-water bottom trawling in the eastern-central Mediterranean Sea and effects of mesh size changes. *Journal of Northwest Atlantic Fishery Science*, *31*, 245.

Edelist, D., Sonin, O., Golani, D., Rilov, G., Spanier, E., 2011. Spatiotemporal patterns of catch and discards of the Israeli Mediterranean trawl fishery in the early 1990s: ecological and conservation perspectives. *Scientia Marina*, 75 (4), 641-652.

Fiorentino, F., Badalamenti, F., D'anna, G., Garofalo, G., Gianguzza *et al*., 2008. Changes in spawning-stock structure and recruitment pattern of red mullet, Mullus barbatus, after a trawl ban in the Gulf of Castellammare (central Mediterranean Sea). *ICES Journal of Marine Science*, 65 (7), 1175-1183.

Gaertner, J.C., Bertrand, J.A., Souplet, A., 2002. STATIS-CoA: A methodological solution to assess the spatio-temporal organization of species assemblages. Application to the demersal assemblages of the French Mediterranean Sea. *Scientia Marina*, 66 (S2), 221-232.

Gorelli, G., Blanco, M., Sardà, F., Carretón, M., 2016. Spatio-temporal variability of discards in the fishery of the deep-sea red shrimp Aristeus antennatus in the northwestern Mediterranean Sea: implications for management. *Scientia Marina*, 80 (1), 79-88.

Gücü, A.C., 2012. Impact of depth and season on the demersal trawl discard. *Turkish Journal of Fisheries and Aquatic Sciences*, 12 (4), 817-830.

Jennings, S., Pinnegar, J.K., Polunin, N. V., Warr, K.J. 2001. Impacts of trawling disturbance on the trophic structure of benthic invertebrate communities. Marine Ecology Progress Series, 213, 127-142.

Kaiser, M.J., Ramsay, K., Richardson, C.A., Spence, F.E., Brand, A.R., 2000. Chronic fishing disturbance has changed shelf sea benthic community structure. *Journal of Animal Ecology*, 69 (3), 494-503.

Kelleher, K. 2005. *Discards in the world's marine fisheries: an update* (Vol. 470). Food & Agriculture Org, Rome, 131pp.

Lauria, V., Garofalo, G., Fiorentino, F., Massi, D., Milisenda, G. *et al.*, 2017. Species distribution models of two critically endangered deep-sea octocorals reveal fishing impacts on vulnerable marine ecosystems in central Mediterranean Sea. *Scientific reports*, 7 (1), 1-14.

Maeda, E. D., Mäntyniemi, S., Despoti, S., Musumeci, C., Vassilopoulou, V. *et al.,* 2017. A Bayesian model of fisheries discards with flexible structure and priors defined by experts. *Ecological Modelling*, 366, 1-14.

Martínez-Abraín, A., Maestre, R., Oro, D., 2002. Demersal trawling waste as a food source for Western Mediterranean seabirds during the summer. *ICES Journal of Marine Science*, 59 (3), 529-537.

Massutí, E., Gordon, J.D., Morata, J., Swan, S. C., Stefanescu, C. *et al.*, 2004. Mediterranean and Atlantic deep-sea fish assemblages: differences in biomass composition and size-related structure. *Scientia Marina*, 68 (S3), 101-115.

Massutí, E., Reñones, O., 2005. Demersal resource assemblages in the trawl fishing grounds off the Balearic Islands (western Mediterranean). *Scientia Marina*, 69 (1), 167-181.

Milisenda, G., Vitale, S., Massi, D., Enea, M., Gancitano *et al.*, 2017. Spatio-temporal composition of discard associated with the deep water rose shrimp fisheries (Parapenaeus longirostris, Lucas 1846) in the south-central Mediterranean Sea. *Mediterranean Marine Science*, 18 (1), 53-63.

Moranta, J., Massutí, E., Morales-Nin, B., 2000. Fish catch composition of the deep-sea decapod crustacean fisheries in the Balearic Islands (western Mediterranean). *Fisheries Research*, 45 (3), 253-264.

Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R. *et al*., 2013. Package 'vegan'. https://cran.r-project.org/web/packages/vegan/index.html

Pillai, S.L., Kizhakudan, S.J., Radhakrishnan, E.V., Thirumilu, P., 2014. Crustacean bycatch from trawl fishery along north Tamil Nadu coast. *Indian Journal of Fisheries*, 61 (2), 7-13.

Pinello, D., Gee, J., Accadia, P., Sabatella, E.C., Vitale, S. *et al.*, 2018. Efficiency of shallow-and deep-water trawling in the Mediterranean and its implications for discard reduction. *Scientia Marina*, 82 (S1), 97-106.

Pitcher, C.R., Ellis, N., Venables, W.N., Wassenberg, T.J., Burridge, C.Y. *et al*., 2016. Effects of trawling on sessile megabenthos in the Great Barrier Reef and evaluation of the efficacy of management strategies. *ICES Journal of Marine Science*, 73 (1), 115-126.

R Development Core Team, 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org

Rochet, M.J., Trenkel, V.M., 2005. Factors for the variability of discards: assumptions and field evidence. *Canadian Journal of Fisheries and Aquatic Sciences*, 62 (1), 224-235.

Rochet, M.J., Catchpole, T., Cadrin, S., 2014. Bycatch and discards: from improved knowledge to mitigation programmes. *ICES Journal of Marine Science*, 71 (5), 1216-1218.

Roda, M.A.P., Gilman, E., Huntington, T., Kennelly, S.J., Suuronen, P. *et al.*, 2019. *A third assessment of global marine fisheries discards*. Food and Agriculture Organization of the United Nations Technical Paper 633, 78 pp.

Sala, A., Brčić, J., Conides, A., De Carlo, F., Klaoudatos, D. *et al.*, 2013. Technical specifications of Mediterranean trawl gears (myGears). *Final project report, financed by the European Commission through the Framework service contract for Scientific Advice and other services for the implementation of the Common Fisheries Policy in the Medi-*

terranean (Contract MARE/2009/05-Lot 1), 519.

Sánchez, P., Demestre, M., Martın, P., 2004. Characterisation of the discards generated by bottom trawling in the northwestern Mediterranean. *Fisheries Research*, 67 (1), 71-80.

Sánchez, P., Sartor, P., Recasens, L., Ligas, A., Martin, J. *et al.*, 2007. Trawl catch composition during different fishing intensity periods in two Mediterranean demersal fishing grounds. *Scientia Marina*, 71 (4), 765-773.

Sartor, P., Sartini, M., Reale, B., Sbrana, M., 2001. Analysis of the discard practices in the Merluccius merluccius (L., 1758) bottom trawl fishery of the northern Tyrrhenian Sea. *Biologia Marina Mediterranea*, 8 (1), 771-774.

Sartor, P., Sbrana, M., Reale, B., Belcari, P., 2003. Impact of the deep sea trawl fishery on demersal communities of the northern Tyrrhenian Sea (Western Mediterranean). *Journal of Northwest Atlantic Fishery Science*, 31, 275-284.

Soykan, O., Bakir, K., Kinacigil, H.T. 2019. Demersal trawl discards with spatial and bathymetric emphasis in the Turkish coast of the Aegean Sea. *Marine Biology Research*, 15, 113-123.

Thrush, S.F., Dayton, P.K., 2002. Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity. *Annual Review of Ecology and Systematics*, 33 (1), 449-473.

Tiralongo, F., Messina, G., Lombardo, B.M., 2018. Discards of elasmobranchs in a trammel net fishery targeting cuttlefish, Sepia officinalis Linnaeus, 1758, along the coast of Sicily (central Mediterranean Sea). *Regional Studies in Marine Science*, 20, 60-63.

Tortora, P., 1989. La sedimentazione olocenica nella plataforma continentale interna tra il promontoria di monte Argentario e la foce del fiume Mignone (Tirreno centrale). *Giornale di Geologia*, 51 (1), 93-117.

Tsagarakis, K., Palialexis, A., Vassilopoulou, V., 2014. Mediterranean fishery discards: review of the existing knowledge. *ICES Journal of Marine Science*, 71 (5), 1219-1234.

Tsagarakis K., Carbonell A., Brčić J., Bellido J. M., Carbonara P. *et al.*, 2017. Old Info for a New Fisheries Policy: Discard Ratios and Lengths at Discarding in EU Mediterranean Bottom Trawl Fisheries. *Frontiers in Marine Science*, 4, 99.

Uhlmann, S.S., Van Helmond, A.T., Stefánsdóttir, E.K., Sigurðardóttir, S., Haralabous, J. *et al.*, 2014. Discarded fish in European waters: general patterns and contrasts. *ICES Journal of Marine Science*, 71 (5), 1235-1245.

Ungaro, N., Marano, C. A., Marsan, R., Martino, M., Marzano, M.C. *et al.*, 1999. Analysis of demersal species assemblages from trawl surveys in the South Adriatic Sea. *Aquatic Living Resources*, 12 (3), 177-185.

Voliani, A., Abella, A., Auteri, R., 1998. Some Considerations on The Growth Perfomance of *Mullus barbatus. CIHEAM-Options Mediterraneennes*, 35, 93-106.

WoRMS Editorial Board 2021. World Register of Marine Species. Available from http://www.marinespecies.org at VLIZ. Accessed 2020-03-09.

Supplementary data

The following supplementary information is available online for the article:

Table S1. List of species found in landings and discards during the whole survey period.
Fig. S1: Species accumulation curve by number of hauls. Blue line represents 95% confidence intervals from standard deviation (standard error of the estimate).