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Spatio-temporal composition of discard associated with the deep water rose shrimp fisheries (*Parapenaeus longirostris*, Lucas 1846) in the south-central Mediterranean Sea

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Abstract

Discarding in fisheries is the fraction of the total catch brought on board and returned to the sea dead or alive for legal or economic reasons. The reduction of discard is one of the main objectives of the European Common Fishery Policy. This study aimed to improve the current knowledge of the discard associated with the deep-water rose shrimp (DPS) fisheries in the south-central Mediterranean Sea. We analyzed data collected from January 2009 to December 2013. Multivariate data analysis and generalized additive models (GAMs) were used to assess the spatio-temporal composition of the discard (which represented 36% of the total catch) and factors influencing its distribution. Multiple analysis of variance highlighted the significant effect of depth factor on discard assemblage. Moreover, in general, bony fish were the most discarded organisms (23.5%), while cartilaginous fish, crustaceans and other invertebrates represented approximately 13% of the total catch. GAMs showed that the fraction of discard in the catch presented significant variation regarding the years, depth and fishing ground. Although the negative trend in discard suggested that the DPS fisheries are moving towards a more sustainable exploitation, the discard fraction in some areas/assemblages remains high. Our results showed that most of the discard was due to species that had a minimum legal size (Hake, DPS, *Trachurus* spp.), and consequently would be subjected to the European discard ban. In order to improve the fisheries management, specific measures aimed to minimize the unwanted catches of undersized species need to be implemented.

Keywords: *Parapenaeus longirostris*, Bottom trawling, Discard ban, bycatch, Self-sampling program.

Introduction

Discarding in fisheries is considered the part of the total catch brought on board but then returned to the sea dead or alive for any reason (Alverson *et al.,* 1994; Kelleher, 2005; Bellido *et al.,* 2011). Discarding practices are mainly a way for fishers to adjust their landings to the legal and market constraints (Rochet *et al.,* 2014). A multitude of factors can affect the practice of discarding, such as complex social, technical, economical, and legislative reasons (Murawski, 1996; Borges *et al.*, 2006; Viana *et al.*, 2011; Feekings *et al.*, 2012; Rochet *et al.*, 2014). In recent decades discard has been considered a main problem in fisheries management, as it accounts for a great part of the overall impact of fishing activities on the environment (Jennings & Kaiser, 1998; Ramsay *et al.*, 1998; Sanchez *et al.,* 2000; Gorelli *et al.*, 2016). Together with socio-economic and ecological matters, discarding is also considered a moral issue, as the waste of natural resources is considered ethically wrong.

The reduction of discarding is one of the main pillars of the new European Union (EU) Common Fisheries Policy (CFP) being considered as prerequisite to long-term, increased catches and profitability for the fishing fleet and improvements in exploitation patterns (Gullestad *et al.*, 2015). The increased importance placed on the reduction of discards in the CFP implies that the focus of fishery management should move from landings to catches, and from fishing yield to fishing mortality (Kelleher, 2005).

Recently Tsagarakis *et al*. (2014) reviewed most of the information available on discards for Mediterranean fisheries. Discarding results highly variable along the basin and among the different fishing gears, with bottom trawls being responsible for the bulk of discards. Despite the importance of demersal fisheries in the Strait of Sicily (Fiorentino *et al*., 2008; Gristina *et al*., 2013), there is little published information on bottom trawling discards, and the existing studies were conducted before the implementation of the EU Reg. 1967/2006 (cod-end from 40 mm diamond to 40 mm square/50 mm diamond). Vitale *et al.* (2006) have estimated an overall discard ratio of 52% produced by commercial bottom trawlers in the Strait of Sicily during early 2000s. For the shrimp fisheries of the Strait of Sicily, Castriota *et al.* (2001) reported a mean discarded biomass value of 49% of the total catches similar to the discard ratio produced by other shrimp trawls in the Mediterranean Sea (43.2±27.2%) but higher than mean values reported for other Mediterranean trawl fishery (32.9±2.8%) (Tsagarakis *et al.,* 2014).

The deep water rose shrimp (DPS), *Parapenaeus longirostris* (Lucas, 1846), is the main target species of the Mediterranean crustacean fisheries, especially in the Strait of Sicily, where it represents more than 60–70% of total landing (Knittweis *et al*., 2013). Deep water rose shrimp is an epi-benthic species with a size-related bathymetric distribution, linked to the ontogenetic migration. The highest densities of DPS larvae have been found around the 100 m isobath. Juveniles move from the continental shelf to the slope, and during the spawning period, the adults move to shallower waters for reproduction (Politou *et al*., 2008; Fortibuoni *et al*., 2010). Available information indicates that DPS fisheries in the Strait of Sicily exploit a single straddling stock of deep water rose shrimp shared among the fishing fleets of Tunisia, Malta, Libya and Italy (Levi *et al*., 1995; Camilleri *et al*., 2008; Fiorentino *et al.*, 2008). Recent assessment of the DPS shared stock status, carried out within the framework of the GFCM and supported by the MedSudMed FAO regional project, has identified a growth overfishing. To improve the exploitation of the stock, a reduction of fishing mortality together with a reduction of undersized shrimp was recommended (Gancitano, 2015).

The increase in size of cod-end mesh is classically considered a powerful system that can reduce the amount of juveniles and improve the exploitation patterns of fished stocks (Beverton & Holt, 1956). The implementation of the EU Reg. 1967/2006 (cod-end from 40 mm diamond to 40 mm square or 50 mm diamond), has driven us to analyze commercial catch data collected from 2009 to 2013, in order to assess the discard composition of the DPS fishery in the Strait of Sicily, and to show any differences with previous work reported in the same area. Updating this knowledge is a prerequisite for dealing with the discard mitigation measures, including the implementation of the landing obligation request by the European Union Common Fisheries Policy (CFP). Furthermore, the ecosystem approach to fisheries management (EAFM) may provide a tool to focus on the ecosystem-fisheries interactions, considering all communities living on the fishing grounds and the relationships that living organisms have both with other organisms and with the habitat where they live. In this context, it is fundamental to expand our knowledge not only on the discarded fraction of commercial species, but also on species without commercial value of the communities exploited by trawling, including sessile benthos structuring the bottom habitat.

Most of the data on commercial catches, landings as well as discards, are classically collected during commercial surveys by seagoing observers. However, due to the cost constrains, they can collect data only in few trips a year onboard of a few vessels. On the other hand fishermen can provide self-sampled data on catch throughout the whole year and for many vessels. Although some concerns were advanced on use of self-sampling/reporting in fishery investigation (Sampson, 2011), an increasing number of studies showed that great advances have been made in using data collected directly by fishers in fishery sciences (Graham *et al*., 2015). In his recent analysis of ups and downs regarding the self-sampling approach in fisheries, Mangi *et al*. (2013) outlined that self-sampling provides i) detailed information on catch and activity, ii) wider sampling coverage than that achievable with observers because small samples can be more easily collected from several vessels, iii) high quality data consistent with observer sampling, vi) strong fishers support and sense of data ownership. On the other hand self-sampling requires i) strict protocols for data collection, ii) voluntary participation leading to concerns about sampling bias, iii) risk of misreporting for contentious, rare or protected species, vi) rapid decline of enthusiasm if expected benefits are not realized, v) needs of verification and auditing to maintain data quality, and vi) an extensive training for fishers.

Adopting a self-sampling approach, our study is mainly aimed at 1) describing the spatio-temporal composition of the discard associated with the DPS trawl fisheries operating in five different fishing grounds traditionally exploited by Italian trawlers in the Strait of Sicily; 2) modeling the discarded fraction in catch as a function of selected predictors (e.g. depth, season).

All of this information can help to mitigate negative effects of discarding and improve the sustainability of demersal fisheries in the main fishing grounds of the south-central Mediterranean.

Materials and Methods

Study area

The Strait of Sicily is an area with a high productivity of fishery resources in the Mediterranean. The large extension of the continental shelf both on the Sicilian and African side which includes offshore fishing banks, the occurrence of stable upwelling and frontal systems enhancing primary and secondary production, the high biodiversity hot spot associated with the ecotonal characteristics of the area between the eastern and western basins (Bianchi, 2007), the complex and diversified benthic biocoenosis (Gristina *et al*., 2004; Garofalo *et al.*, 2007), are important factors contributing to the observed high fisheries yield.

Concerning the topography of the sea bottoms, the continental shelf along the southern coasts of Sicily is wide and characterized by the Adventure and Malta banks, respectively on the western and eastern side, separated by a narrow shelf strip in the middle. The African shelf is wide along the Tunisian coasts and, with the exception of the Sirte Gulf, it becomes narrower along the Libyan coasts. The continental slope is generally steeper and more irregular between Sicily and Tunisia and along the eastern side of the Maltese bank than in the area between Malta Island and the Libyan coasts.

Deep water rose shrimp fleet description

In the Strait of Sicily, DPS fishing is carried out mainly by Italian bottom otter trawlers (Knittweis *et al.*, 2013). These trawlers operate on the outer continental shelf and upper slopes on both the European and African sides of the Strait of Sicily (Fig.1).

Two main segments of the Italian fleet are operating in the Strait of Sicily: i) Sicilian small trawlers, with an overall length (LOA) between 18 and 24 m fishing mainly on short-distance fishing trips, which range from 1 to 2 days at sea; ii) Sicilian large trawlers with LOA > 24 m which have longer fishing trips that may have a duration of up to 4 weeks. These large trawlers are mostly based in Mazara del Vallo (south-western Sicily) and operate offshore, in both Italian and international waters of the south-central Mediterranean Sea at depth generally ranging from 200 to 400 m.

The Italian trawlers operating in the area and targeted to DPS ranged from 240 vessels in 2009 to 200 in 2013, being the trawlers with LOA > 24m about the 60% of them.

Sampling procedure

Catch composition data were derived from Italian bottom trawlers operating in the Strait of Sicily, and were collected within the module of commercial catch monitoring (Campbiol) of the European Data Collection Framework (DCF) between January 2009 and December 2013. Owners of vessels involved in the bottom trawling fisheries were contacted and invited to participate in a self-sampling program of catches, in terms of both landed and discarded fraction. Skippers and fishers voluntary participating in the program were trained by CNR staff to ensure consistency of the provided information. Written sampling protocols and standardized forms were used. Two kinds of forms were delivered to fishers. First form, called "Landings Trip Form" (LTF), contained information by trawler regarding the date of departure and return of fishing trip, the fishing-ground and depth range per trawl, the number of hauls and the detailed composition of landings by species and commercial categories by trip. For each fishing trip one or more boxes of commercial category of the DCF target species, including the DPS,

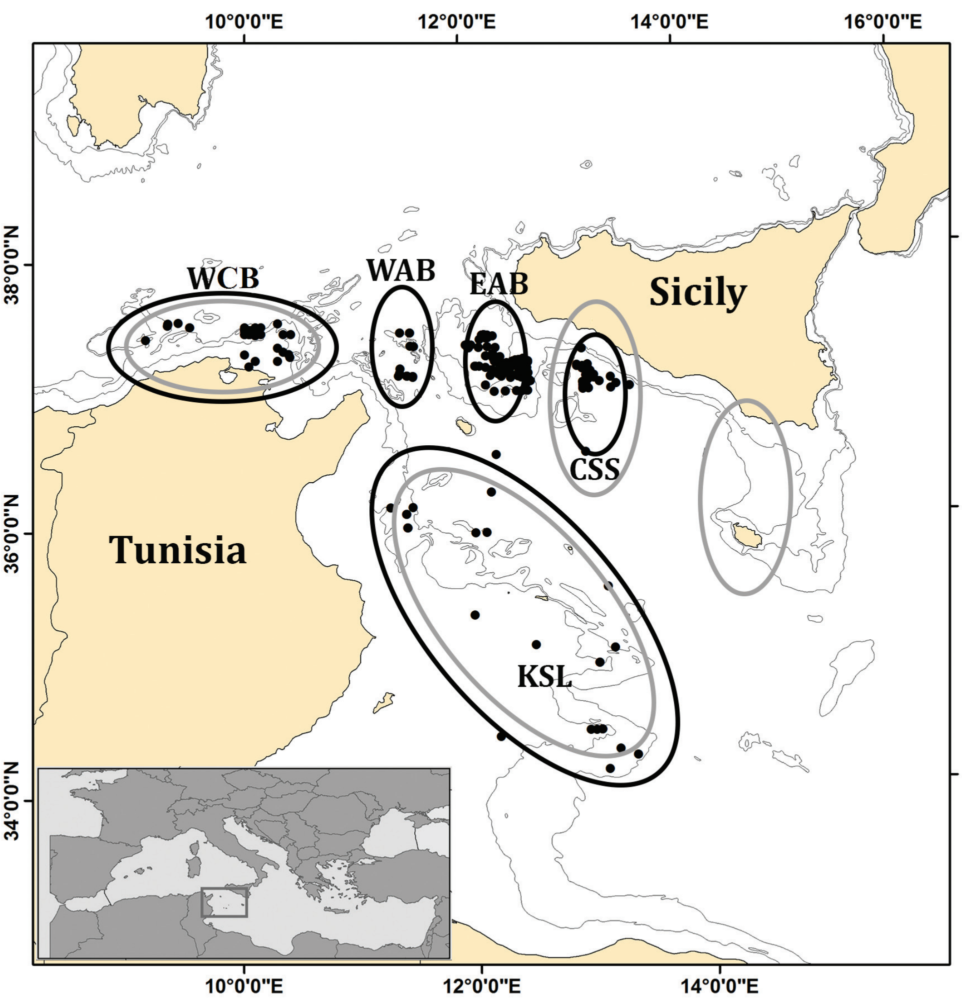

Fig. 1: Grey circles: the main fishing areas of *Parapenaeus longirostris* for Sicilian trawlers in the south-central Mediterranean (modified from Fiorentino *et al.,* 2011). Black circles: the fishing areas considered in the present study (WCB: Western Cape Bon; WAB: Western Adventure Bank; EAB: Eastern Adventure Bank; CSS: Central Southern Sicily Coast; KSL: Kelibia and South Lampedusa). Black point: analyzed hauls.

were randomly taken by the CNR technicians at landing in order to reconstruct the total composition in species and size of the commercialized fraction. The information contained in the LTF was integrated with a second form, called "Discards Haul Form" (DHF), containing data on the volume of the total discards collected in a selected haul during the self-sampled trip. A sample of about 25 litre of discard was randomly taken from the total discard sampled and delivered at landing to CNR technicians together with the DHF sheet. The information of DHF combined with the samples of discarded fraction were used to estimate the species composition and abundance of total discard fraction (in kg) for the haul and successively, knowing the number of the haul carried out for each trip, used to estimate the total discard for the fishing trip.

Samples of discard and commercial catch were sorted and weighed by species and category in the laboratory of the CNR-IAMC of Mazara del Vallo. In order to distinguish among the entire set of monitored vessels those targeting the DPS, we calculated the percentage of commercial DPS in each trip and, hence, the median value of the distribution of percentages in the total set of data. Successively, we selected from the total set of vessels, the trawlers targeting the DPS as those in which the percentage of DPS in landing was higher than the median. This subset of vessels was considered in all successive analyses.

The catch composition of 144 hauls sampled for discards, with a depth of between 50 and 650 meter, was expressed in Kg of each species for 1 fishing day (Kg/day). In order to reduce the effects caused by different durations of hauls, the values of discarded and commercial species biomass were expressed as percentage of the haul's catch.

To validate data derived from self-sampling protocol, we have compared them with data collected by on-board observers in a subset sample, amounting to about 26% of observations during the DCF in the Strait of Sicily. This data covered all zone considered in the manuscript, and also all bathymetric strata. Analysis of variance was used to test any significant differences between discard ratio collected with and without on-board observer in each bathymetric strata (interaction Type of sampling Vs Bathymetric strata). Results showed that differences between two series of discard ratio were not significant in each bathymetric strata (F_2 0.46 ; p value 0.49).

Discard data analysis

Firstly, the average discard ratio in the whole area and throughout the investigated time was obtained by the classical Ratio Estimator (R) (Cochran, 1977), as:

$$\hat{R} = \frac{\sum_{K=1}^{n} D_k}{\sum_{K=1}^{n} (C_k)} \qquad (1)$$

Being *k* a given sampled trawlers, *n* the total number of sampled trawlers, *D* and *C* the discarded fraction and the total catch in kg, respectively.

The corresponding variance was calculated as:

$$Var[\hat{R}] = \frac{(1-f)}{n\bar{C}^2}(s_D^2 + \hat{R}^2 s_C^2 - 2\hat{R}s_{DC}) \qquad (2)$$

with f = 0; Ĉ = mean of catches; S_D= sampling variance of discards; S_C= sampling variance of catches and S_{DC}= sampling covariance.

Then, we looked for a cluster emerging from discard through hierarchical cluster analysis and non-metric multidimensional scaling (nMDS). These analyses were based on the Bray-Curtis similarity of square root transformed data of percentage abundance by species (Clarke & Warwich, 2001).

Multiple analysis of variance (Anderson, 2001; PRIMER software) was performed in order to highlight significant differences of the discard assemblage among covariates. Data were analyzed using 4-way permutational multiple analysis of variance (PERMANOVA, Anderson, 2001). The four factors considered were: year, fixed with five levels (2009, 2010, 2011, 2012 and 2013); season, fixed and orthogonal with four levels (winter, spring, summer and autumn); depth, fixed and nested in zone, with three levels suggested by cluster analysis (0–150; 151–300; >301 meter); zone, fixed and nested in season, with five levels (zone 1=Western Cape Bon (WCB); zone 2=Western Adventure Bank (WAB); zone 3=Eastern Adventure Bank (EAB); zone 4=Central Southern Sicily Coast (CSS); zone 5=Kelibia and South Lampedusa (KSL), Fig. 1).

Moreover, the species that contributed more to the similarity among samples inside the groups have been characterized using the SIMPER routine (Clarke, 2003).

Discard modeling

The protocol described in Zuur *et al.* (2010) was used to explore data. The presence of outliers and relationships between variables was assessed using Cleveland dotplots, boxplots and multi-panel scatter plots, while relationships between covariates were investigated using Pearson correlation coefficients and the variance inflation factor (VIF). We assessed whether the percentage of discard in a given year was related to the percentage of discard in subsequent years by calculation the auto-correlation function (ACF) derived from normalized residuals (Zuur *et al.,* 2009).

We formulated an *a priori* set of models based upon the environmental, spatial and biological variables. Successively, models were ranked and the best model was selected by using Akaike's information criterion (AIC). As our data presented a nonlinear pattern we adopted generalized additive models (GAMs) to carry out the analyses.

Our data on discard ratio was calculated as:

$$Discard\ fraction = \frac{Discard\ weight}{Discard\ weight + Commercial\ catch\ weight} \qquad (3)$$

This index consists of proportion data ranging between 0 and 1. Because this type of ratio is not based on a proportion of successes, the assumption of a binomial distribution does not hold. Instead, we fitted the GAM by specifying a beta

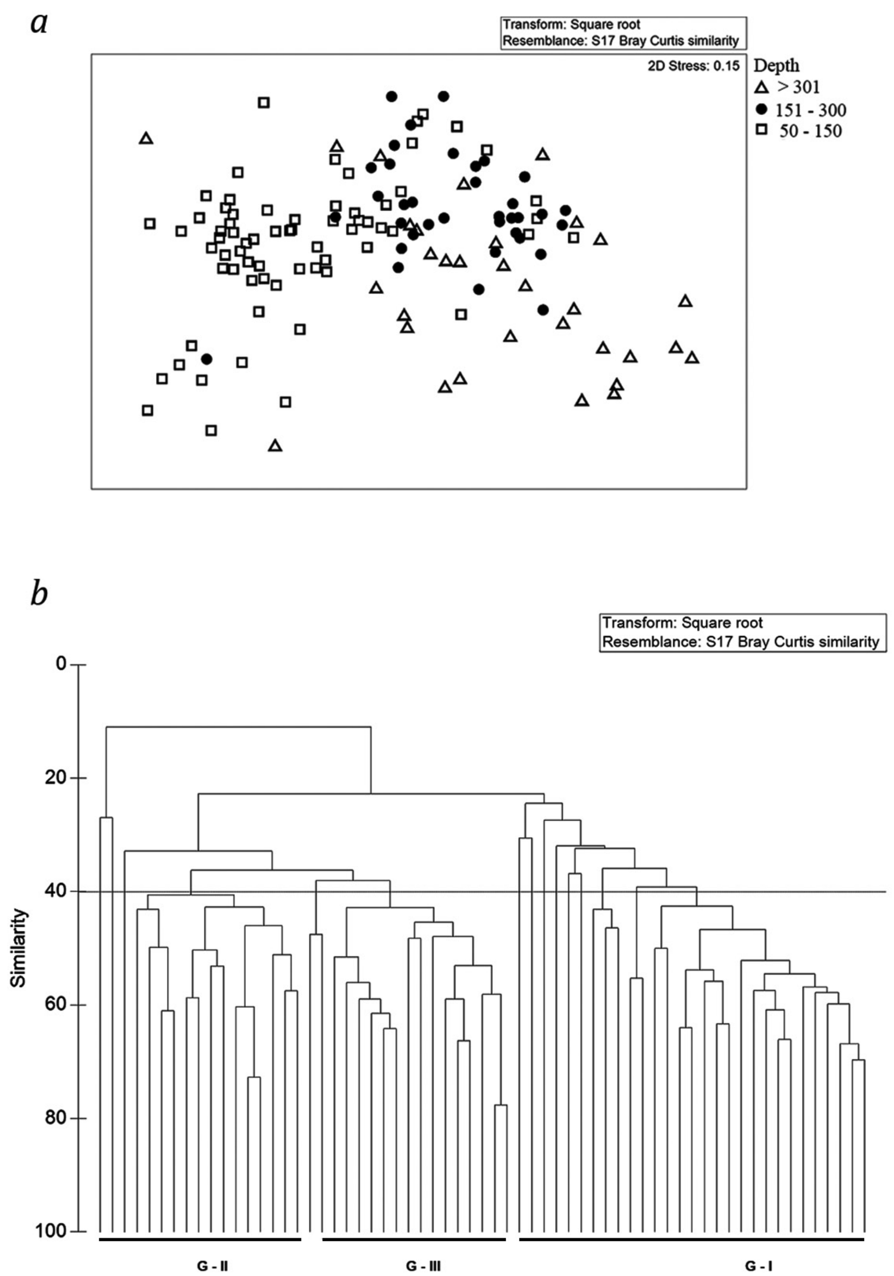

Fig. 2: A: Non-parametric multi-dimensional scaling results. Empty square symbols: depth range 60–150 meters; filled circles symbols: depth range 151–300 meters; empty triangles symbols: depth range 301–600 meters. B: Cluster analysis results. G-I: 60–150 meters; G-II: 151–300 meters; G-III: 301–600 meters.

distribution, which is mostly used for this kind of data. Moreover, the beta distribution ranges in interval (0,1), with 0 and 1 excluded. This range was suitable for our data because we observed neither 0 nor 1 when calculated (1). All statistical tests were conducted using the mgcv library (Wood, 2006) in R (v3.2.0; R Development Core Team, 2013) and tests were considered significant at the $P < 0.05$ level.

Results

In our study a total of 345 species were caught and identified. A complete list of all identified species is reported in Annex 1 (Supplementary Material). Fifty species were landed and 331 were discarded. The discarded fraction of commercial species was composed of both non-marketable undersized specimens of target species and by-catch species not landed because of their low commercial value.

Cluster analysis and nMDS grouped all samples in three clusters characterized by different bathymetric levels: G-I= 60–150 meters; G-II=151–350 meters; G-III=351–650 meters (Fig. 2a and b). The level of similarity inside each group was greater than 40%.

Discard composition in the Strait of Sicily showed no significant difference among years, seasons and zones (p-value > 0.05, Table 1). Multiple analysis of variance highlighted a significant effect on discard assemblage only for the factor of depth (p-value <0.05, Table 1).

Overall, the average discard ratio represented 36 % of the total catch. Considering the depth separately, the deepest waters (G-III) displayed the highest discard ratio (~44 %), whereas the smallest percentage was encountered in shallow and middle waters (~ 34%). Overall, zone 4 (CSS) presented smallest percentage of discard (~28 %), while zone 1 (WCB) the highest one (~43%). On average, the amount of discard in kilograms (mean±standard error) for one fishing day was: 208.9±22.4 Kg (WCB), 141.4±62.4 Kg (WAB), 135.7±16.1 Kg (EAB), 94.9±13.5 Kg (CSS) and 328.6±52.9 Kg (KSL), while the commercial amount was: 275±12.2 Kg (WCB), 319.5±109.1 Kg (WAB), 256.4±13.7 Kg (EAB), 238.9±21.6 Kg (CSS) and 490.6±82.1 Kg (KSL).

In general, bony fish were the most discarded organisms (23.5%). The highest discard ratio of bony fish were recorded at shallow water of zones 1 (WCB), 5 (KSL) and 2 (WAB). Cartilaginous fish, crustaceans and other invertebrates represented approximately 13% of the total catch. Discard of cartilaginous fish was the highest in the deepest water, and especially in Zone 3 (EAB).

The SIMPER analysis (Table 2) showed that *Trachurus trachurus* was the discarded species that mainly characterized the G-I and G-II stratum, with a 40.87% and 14.84% of contribution to the similarity respectively (Table 2). The shallow waters (G-I, G-II) were also characterized by discard of *Parapenaeus longirostris* and *Merluccius merluccius*. The most representative species of G-III strata was *Phycis blennoides,* followed by *Helicolenus dactylopterus*, *Trachurus trachurus, Galeus melastomus*, and *Lepidopus caudatus*.

Eleven different models (Table 3) have been formulated to explain the variation of the discarded fraction of catch in the DPS fishery. After an AIC-based model selection, Model 9 (Table 3) was shown to be the most parsimonious. Then, we passed to model validation, checking for homogeneity, independence of variables, normality and influential observations (Supplementary Material).

Model 9 has an adjusted R-square of 0.61, and the deviance explained by this model is 67.2%. This model assumes that the discard fraction in the catch is a function of depth (function calculated in all zones considered in the study), zone, years, and of the percentage of commercial DPS in the catch. On the basis of statements of fishers who reported that fishing grounds producing the highest yield of DPS show the lowest amount of other species, we decided to include this last variable to take into account a measure of success of the haul, in order to test whether high production zones of commercial DPS present different percentage of discard with respect to the low production zones. We also tested the same model substituting the percentage value of all other commercial species (M11) in place of the fraction of *P. longirostris*. The AIC value of this model was higher than M9 and, moreover, the relation between discard and commercial fraction (without *P. longirostris*) was not significant (p=0.4), suggesting a correlation only between discard and commercial DPS (p<0.001). Table 4 shows p-values for each variable included in the model.

The ratio of discard in the haul was highly negatively correlated with the percentage of commercial rose shrimp in the catch (Fig. 3). In fact, when the fraction of commercial *P. longirostris* was less than 20%, discard reached the highest value, while a DPS increase was directly correlated with a decrease of discard. However, no significant correlation was found between the fraction of discard and the fraction of other commercial catch.

The fraction of discard in the catch presented significant variation among the years (p_{value} > 0.01). Specifically, we found a significant low value in the 2010 (Fig. 5F). Rose shrimp fishery was also characterized by different ratio of discard in the catch between different zones, with the highest median values in zones WCB and KSL, while other three zones were similar among them but with smaller discard ratio (Fig. 4).

Table 1. Permanova results comparing the discard composition. The level of significance was set at 0.05.

Factor	DF	F VALUE	P VALUE
YEAR	1	1.27	0.30
SEASON	2	1.67	0.12
Zone $_{(season)}$	11	0.77	0.73
Year: Season	8	2.11	0.30
Depth $_{[zone(season)]}$	15	1.95	0.001
Year: Zone $_{(season)}$	16	1.31	0.28
Year: Depth $_{[zone\ (season)]}$	4	0.89	0.59

Table 2. Results of SIMPER analysis. G-I = 0–150; G-II = 151–300; G-III >301 meter.

Deep								
G-I			G-II			G-III		
Specie	Contrib%	Cum.%	Specie	Contrib%	Cum.%	Specie	Contrib%	Cum.%
T. trachurus	40.87	40.87	*T. trachurus*	14.84	14.84	*P. blennoides*	22.10	22.10
M. merluccius	6.72	47.60	*M. merluccius*	11.51	26.35	*H. dactylopterus*	11.00	33.09
P. longirostris	6.47	54.07	*P. longirostris*	10.50	36.85	*T. trachurus*	7.42	40.51
L. cavillone	4.65	58.72	*G. argenteus*	7.88	44.73	*G. melastomus*	6.75	47.26
S. flexuosa	4.46	63.18	*L. caudatus*	6.26	50.99	*L. caudatus*	6.12	53.38

Table 3. Models applied to fraction of discard in the deep rose shrimp fisheries. The index j represents area (j=1,…,5). The notation $f(Depth_s)$ means that depth is modeled as a smoothing function. The notation $f_j(Depth_s)$: $Zone_j$ means that one smoother is used for each zone. The notation $f(Years_s)$ means that the Year is modeled as a smoothing function.. The notation $f_j(PF_s)$: $Zone_j$ means that one smoother is used for each zone. **FD**=discarded fraction; **FP**= commercial *P. longirostris* %; **FComm**=commercial fraction without *P. longirostris* %.

	Model	*AIC*
M1	$FD_{is} = f(Depth_s) + a_i + \varepsilon_{is}$	*-151*
M2	$FD_{is} = f_j(Depth_s) : Zone_j + a_i + \varepsilon_{is}$	*-142*
M3	$FD_{is} = f_j (Depth_s) : Zone_j + f_j (Years)+ a_i + \varepsilon_{is}$	*-156*
M4	$FD_{is} = f_j (Depth_s) : Zone_j + Zone + f_j (Years)+ a_i + \varepsilon_{is}$	*-162*
M5	$FD_{is} = f(FP_s) + a_i + \varepsilon_{is}$	*-198*
M6	$FD_{is} = fj(FP_s) : Zone_j + a_i + \varepsilon\ is$	*-190*
M7	$FD_{is} = f_j (FP_s) : Zone_j + fj\ (Years)+ a_i + \varepsilon_{is}$	*-196*
M8	$FD_{is} = f_j (FP_s) : Zone_j + Zone + f_j (Years)+ a_i + \varepsilon_{is}$	*-205*
M9	$\mathbf{FD_{is} = f_j (FP_s) : Zone_j + Zone + f_j (Years)+ a_i + \varepsilon_{is}}$	***-255***
M10	$FD_{is} = f_j (Depth_s) : Zone_j + Zone + f_j (Years)+ f_j (FP_s) : Zone_j + a_i + \varepsilon_{is}$	*-220*
M11	$FD_{is} = f_j (Depths) : Zone_j + Zone + f_j (Years)+ FComm_s + a_i + \varepsilon_{is}$	*-197*

Table 4. Statistical results of selected model (M09).

Factor	Df	Chi.sq	P value
S(Year)	3.06	27.91	<0.001
Zone	4	15.98	0.003
s(Depth):factor(zone)1	1	0.86	0.35
s(Depth):factor(zone)2	3.79	6.13	0.09
s(Depth):factor(zone)3	1	13.07	<0.001
s(Depth):factor(zone)4	1	0.54	0.45
s(Depth):factor(zone)5	3.19	8.90	0.03
FP	1	94.01	<0.001

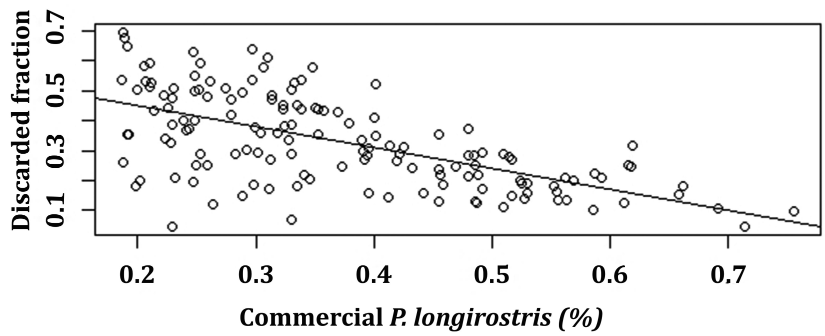

Fig. 3: Regression relationship between the discard fraction and commercial DPS percentage in the catch.

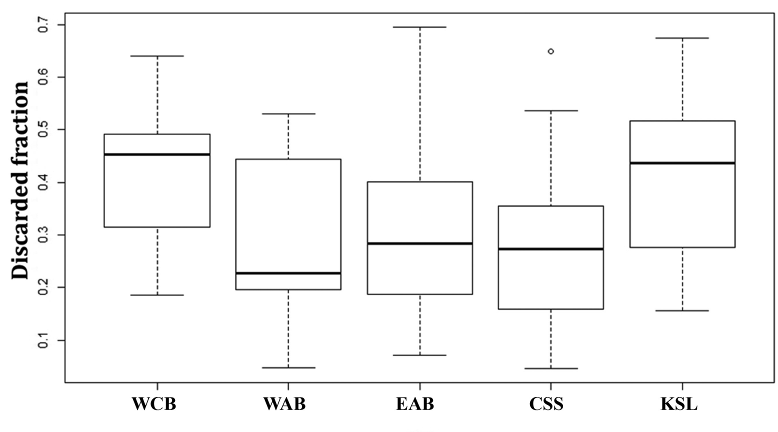

Fig. 4: Spatial trend of discard fraction in the DPS fisheries.

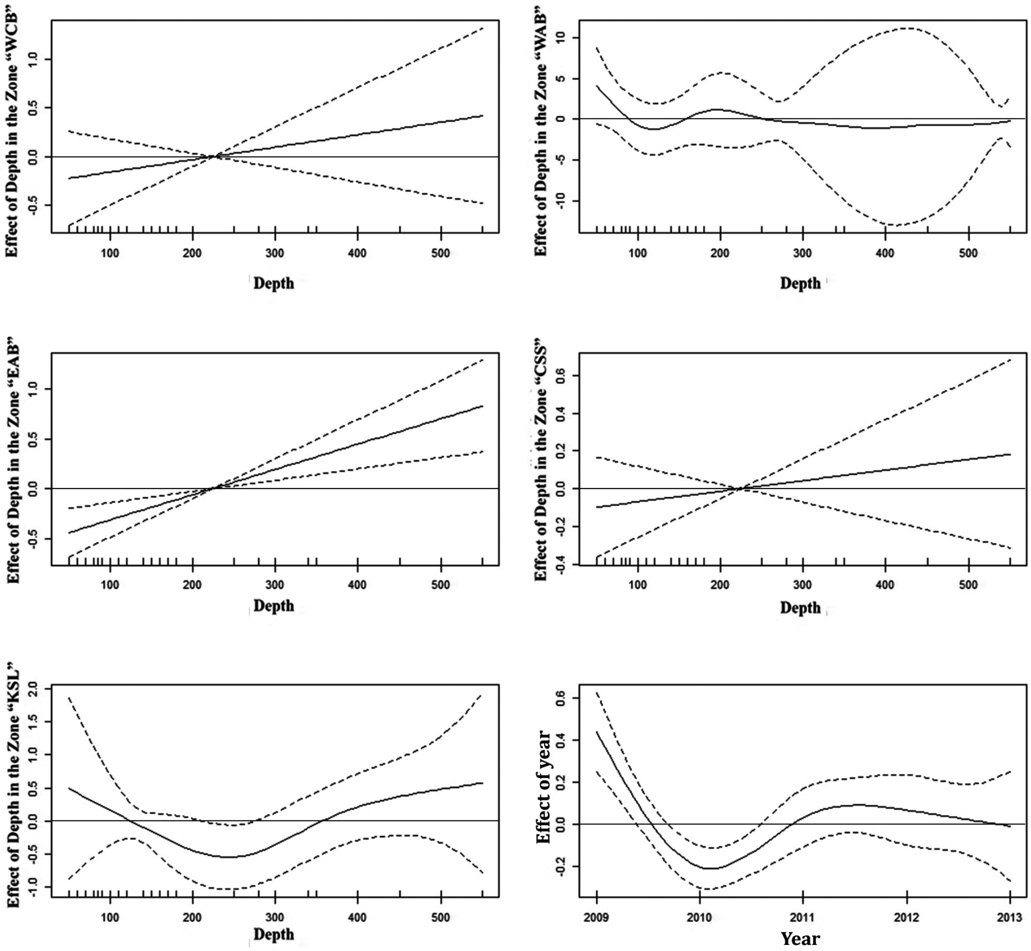

Fig. 5: Smoothed fits of covariates modelling. Tick marks on the x-axis are observed datapoints. The y-axis represents the spline function. Dashed lines indicate 95% confidence bounds. A-E: discard ratio in the hauls as a function of the depth, respectively in zones 1–5; F: discard ratio in the hauls as a function of time.

Depth significantly affected the discard fraction only in EAB and KSL zones (Figs. 5c and e).

In zone EAB, discard percentages were positively correlated with depth, with low values close to the coast and highest values at deepest level.The discard fraction presented one minimum point in zone KSL. Discard in the catch decreased 50 to 250 meters and then increased again until 400 meters.

Discussion

Several examples of self-sampling approach in fishery science are available in recent literature. Reporting experiences gathered in New Zeeland, Starr (2010) stated that, even if self-sampling programs need supervision and support in order to succeed, the data on biological features of catches proved very useful for stock assessment. In the Irish Sea, Hoare *et al*. (2011) showed that the species composition and amount of discard derived from data collected through self-sampling and those by scientific observers were very similar for otter trawls and Scottish seines. Similarly, Uhlmann *et al*. (2011) did not observe any difference in the length structure of catches collected by self-sampling and scientific observers in the Netherlands. Unbiased reporting of catch was found by Lordan *et al*. (2011) for self -sampling in the Norway lobster trawl fisheries off the Irish Sea. According to Kraan *et al*. (2013), self-sampling methodology and observer sampling clustered in the southern North Sea. Furthermore, observers tended to overestimate total catch volumes, and seemed to underestimate benthic invertebrate discard numbers. In the Adriatic Sea, Mion *et al.* (2015) compared the catch data from fishers self-sampling and observers on-board in otter trawler and did not find any significant difference between the two data set.

The species composition of discarded fraction associated with the DPS fishery in the Strait of Sicily was quite stable in all the investigated fishing grounds during the 5 years considered. Stability of the discarded composition reflects the persistence of demersal assemblages over time in different areas of the Mediterranean Sea (García-Rodríguez *et al.,* 2011). In all years, the multivariate analysis showed that depth is the main structuring factor for the spatial distribution of assemblages fished by trawlers targeted towards DPS. This result is consistent with the role attributed to depth in characterizing species assemblages on the continental shelf and upper slope of the western and north-western Mediterranean (Demestre *et al.,* 2000; Biagi *et al.,* 2002; Massutí & Reñones, 2005; Garces *et al.,* 2006; García-Rodríguez *et al.,* 2011).

The predominant part of discard in the DPS fisheries was represented by bony fish in all. *Trachurus trachurus* was the most abundant species caught in the entire sampling, followed by *Merluccius merluccius.*

Elasmobranchs are organisms that are very susceptible to fishing impact, and because of their low fecundity, high length and age at first maturity, elasmobranchs are vulnerable to trawlers' activity (Stevens *et al.,* 2000; Gristina *et al.,* 2006). The present study can be useful to highlight the zones and depth where they are discarded in a great percentage, and to support a better strategy for the protection of this group.

In the shelf break, chondrichthyes were replaced by crustacea, and especially by *Parapenaeus longirostris*, *Munida intermedia* and *Plesionika heterocarpus*. The discard fraction of rose shrimp was composed largely by juveniles in the shelf break, in accordance with the known presence of its nurseries in this depth range (Fortibuoni *et al*., 2010; Garofalo *et al*., 2011; Colloca *et al*., 2015).

Discard fractions found in the present work are smaller than those previously reported in the Strait of Sicily (Castriota *et al.,* 2001; Vitale *et al.,* 2006) prior to 2009, but similar to those obtained by Sánchez *et al*. (2004) at the same bathymetric strata. The GAM model has also highlighted a minimum value in 2010. The decrease of the non-commercial fraction could be due to the adoption of the minimum legal mesh size in the codend of 40 mm square or 50 mm diamond more selective than the previous 40 mm diamond in June 2010 (Regulation CE 1967/2006). However the adoption of lighter trawl nets from the Italian trawlers targeting to DPS to decrease the consumption of fuel during the fishing trip could be have a synergic effect in the observed reduction of the discarded fraction in bottom trawlers' catches.

The relationship between discard fraction and depth detected in the GAM model was highly significant in zones 3 (EAB) and 5 (KLS) (p value < 0.01). In these two zones, the depth of fishing grounds increases with the distance from the coast. The trawlers fishing far from the coast have a trip that can reach 1–1.5 month. In this case, fishers store on board only organisms with high commercial value, while species of low economic value are discarded to save space in the freezer. On the contrary, in the G-I strata (close to coast) fishers can also land organisms with low economic value, because they do not have a problem with space on board. A positive correlation between discard fraction and depth has been found also by D'Onghia *et al*. (2003), who justified this trend with the greater presence of unwanted species, such as *Hoplostethus mediterraneus* and *Galeus melastomus*. Similarly, the deeper waters of the Strait of Sicily where rose shrimp fisheries work, are characterized by a great abundance of *Galeus melastomus, Coelorhynchus coelorhyncus, Phycis blennoides* and *Gadiculus argenteus.* Since the fishing ground in zones WCB was located far from the coast, in this case, the depth variation did not play an important role.

Discard ratio also changed among the fishing grounds considered and can be correlated with the period that the boat stays in the sea to work. Trawler fleets working in zones WAB, EAB and CSS are close to the principal harbor of southern Sicily, Mazara del Vallo and Sciacca. These boats can return to the port more frequently than the fleet operating in zones 1 and 5 (WCB and KSL). In the first case, fishers can also decide to land organisms with low commercial value, while in the second case, they primarily prefer to land organisms with high economic value, with the consecutive increasing of discard. These two different strategies, adopted among different bathymetric strata or fishing grounds, can affect the characterization and the presence of discard present in the catch.

Percentages of discard found in this study for single haul varied between 5% and 70%, with a mean of 36%. These values are in agreement with the discard ratio encountered in another study analyzing shrimp trawl fisheries (Tsagarakis *et al.,* 2014).

The inverse relationship between the fraction of commercial catch of DPS and the discard fraction is very interesting. This result can be explained by two different hypotheses: 1) the environmental hypothesis, according to which the characteristic of the environment that sustains a great density of this target species (*P. longirostris*) is not equally favorable to other organisms, including those that are part of the discard; 2) the "effort" hypothesis, according to which the intensive trawl fishery in the zones where the stock of deep rose shrimp is present, is so high that it can completely change the demersal community, reducing the density of principal discarded species associated with *P. longirostris,* and leaving as a final result, fishing grounds where it is possible to catch a great amount of shrimp with a low fraction of unwanted species.

Although the negative discard trend in the examined period suggests that the DPS fisheries are moving towards a more sustainable exploitation, the discard fraction in some areas/assemblages remains high. Our results showed that most of the discards in the DPS fisheries are due to species that have a minimum legal size (Table SM1), according to the Re. CE 1967/2006 (Hake, *P. longirostris*, *Trachurus* spp.), and are consequently subjected to the discard ban (art. 15 of the reg. EU 1380/2013). To avoid the landing of discards, specific measures aimed at minimizing the unwanted catches of undersized horse mackerel, hake and deep water rose shrimps should be implemented (art. 14 of the reg. EU 1380/2013). In order to achieve this objective in the DPS fishery in the Strait of Sicily, a spatial based approach, including the closure of the nurseries of main commercial species to bottom trawling is considered the most promising management measure (Garofalo *et al*., 2011; Russo *et al*., 2014).

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