Discards regulation vs Mediterranean fisheries sustainability
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Reducing unwanted catches of trammel nets: experimental results of the "guarding net" in the caramote prawn, *Penaeus kerathurus*, small-scale fishery of the Ligurian Sea (western Mediterranean)

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Summary: This study aimed to test the effectiveness of a "guarding net", a device placed at the bottom of a trammel net, for reducing unwanted catches in the caramote prawn trammel net fishery of the Ligurian Sea. This specialized and profitable fishery is affected by unwanted catches that generate high discard rates and damage to the nets, with environmental impacts and costs for fishermen. The experimental study consisted in comparing the catches of a standard trammel net (STN) with those of two "experimental" trammel nets, e.g. STNs provided with a guarding net of 19 cm (TGN20) and 24 cm height (TGN25), respectively. The guarding net, a strip of gillnet placed at the bottom of the net, can be considered a by-catch reducer device (BRD). Some fishermen of the investigated fishery have been using this device for several years. The results of the 15 experimental fishing trials performed from June to July 2016 indicate that the guarding nets significantly reduce discards (e.g. crabs and other invertebrates); the biomass of the unwanted species caught was 75% lower than that produced by the STN. The catch rates of the target species obtained with TGN20 and TGN25 were also significantly lower than those of the STN, though of a lesser amount. Nonetheless, this economic loss can be compensated by the decrease in sorting time and material and labour costs that can be achieved using the guarding net.

Keywords: experimental fishing; discards; trammel net; caramote prawn; small-scale fisheries; Mediterranean Sea.

Reducción de los descartes en la pesca con trasmallo: resultados experimentales utilizando trasmallo con "faldón" en la pesca artesanal del camarón, *Penaeus kerathurus*, en el mar Ligur (Mediterráneo Occidental)

Resumen: El objetivo de este trabajo fue testar los efectos de un "faldón", una red colocada en la parte inferior de un trasmallo, para reducir los descartes en la pesquería del camarón del mar Ligur. Se trata de una pesquería especializada y rentable, afectada por capturas no deseadas, que generan descartes y daños a las redes, con impacto ambiental y costes para los pescadores. Se llevaron a cabo pescas experimentales, para comparar la captura de un trasmallo estándar (STN) con la de dos trasmallos "experimentales", construidos a partir de un trasmallo estándar, con el ajuste de un faldón de 19 cm de altura (TGN20), y de un faldón de 24 cm (TGN25). Este faldón, una banda de red de enmalle, se puede considerar como un dispositivo reductor de capturas accesorias (BRD). Algunos pescadores de la pesquería investigada ya utilizan este dispositivo desde hace algunos años. Los resultados de las quince pruebas experimentales, realizadas de junio a julio 2016, muestran que el faldón de red de enmalle contribuye significativamente a reducir los descartes (cangrejos y otros invertebrados), con una reducción de la biomasa de las especies descartadas hasta el 75%, respecto al trasmallo estándar. Al mismo tiempo, también las tasas de captura de las especies objetivo obtenidas con TGN20 y TGN25 fueron significativamente más bajas que las del STN, aunque de menor magnitud. Sin embargo, esta pérdida económica puede ser compensada por la disminución del tiempo de trabajo, de los costes del material y de la mano de obra, que se pueden lograr utilizando un trasmallo con "faldón".

Palabras clave: pesca experimental; descartes; trasmallo; camarón; pesca artesanal; mar Mediterráneo.

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INTRODUCTION

Discarding is a consequence of fishing activities that consists in bringing marine fauna on board fishing vessels and subsequently returning it to the sea; it may constitute a large amount of the total catch (Alverson et al. 1994, Hall 1999, Kelleher 2005). Discards include commercial species and species without commercial value. The reasons for discarding are numerous and involve legal aspects (e.g. catches under the minimum landing size or exceeding quotas), economic (low market value, high grading), technical aspects (e.g. type of gear, vessel capacity), and environmental aspects (e.g. weather conditions affecting sorting practices) (Stratoudakis et al. 1998, Vassilopoulou et al. 2012, Bellido et al. 2014).

One of the primary factors affecting discarding is the type of fishing gear. The otter trawl is undoubtedly the gear responsible for most discards (Kelleher 2005). In the Mediterranean, the available studies report a discarded fraction for trawling ranging from 20% to 40% of the total biomass caught (Machias et al. 2001, Sánchez et al. 2004, Tsagarakis et al. 2008, among others).

It is widely accepted that the passive gears (e.g. trammel nets, gill nets, longlines and traps) used by the small-scale fisheries are more selective, especially if compared with towed gears (Bellido et al. 2011). However, it has been documented that passive gears may also produce noticeable amounts of discards (Tzanatos et al. 2007, Batista et al. 2009, Villasante et al. 2015, among others). According to the EC (2007), the biomass discarded by trammel net fisheries in Mediterranean ranges from 15% to 25% of the total catch, compared with around 10% for the gill net. In fact, catches of set nets often show high percentages of non-commercial species, mostly invertebrates (crabs, gastropods and holothurians) belonging to the coastal macrobenthic species assemblages.

Discards are generally considered a waste of fish resources and inconsistent with responsible fisheries (Kelleher 2005); they contribute to the depletion of marine populations and can alter the overall structure of trophic webs and habitats (Bellido et al. 2011); discarding also has economic effects, because only a fraction of the potentially commercial catch is landed. Reduction or elimination of discards is an ecological, socio-economic and moral priority (Kelleher 2005); it is one of the core aspects of the Ecosystem Approach for Fishery Management (Garcia et al. 2003) and of the reform of the Common Fisheries Policy (CFP, EU Reg. 1380/2013). The CFP reform obliges fishermen to land all the discards of undersized specimens, thus enabling fishermen to play an active role in reducing and managing discards. Discards can be reduced in different ways, primarily by improving gear selectivity and through spatio-temporal closures to decrease fishing mortality for some species or age classes (e.g. juveniles).

Several technical solutions aimed at reducing unwanted catches, i.e. "by-catch reducer devices" (BRD, Crespi and Prado 2002), have been implemented in the trawl fisheries. Studies aimed at reducing discards of set nets are still few in number, mostly dealing with gillnets (Erzini et al. 1997, Batista et al. 2009, Grati et al. 2015). For trammel nets, one of the few technical solutions could be the "guarding net", a strip of monofilament net with large meshes placed in the lower part of the net, just above the lead line. The first studies of this device have shown promising results in reducing unwanted catches. The guarding net gives a higher likelihood of escape to species living close to the bottom, which are mostly composed of non-commercial benthic invertebrates. Sartor et al. (2007) reported a reduction of about 50% of the discards for the common sole fishery in the Ligurian Sea; Metin et al. (2009) reported a decrease of about 50% of the catch of crabs for the caramote prawn fishery in the Aegean coasts of Turkey; and Aydin et al. (2013) reported a 50% to 60% reduction of discards in the trammel net fisheries of Izmir Bay, Aegean Sea, Turkey.

In some fisheries of the Mediterranean, professional fishermen are using trammel nets provided with guarding nets. One example is the fishery targeting the caramote prawn, *Penaeus kerathurus*, performed with trammel nets by the small-scale fishery of Viareggio, Ligurian Sea, Italy (Rossetti et al. 2006). It is a seasonal, highly remunerative and specialized fishery in terms of gear characteristics and fishing practices (Rossetti et al. 2006, Bolognini 2017). Unfortunately, the catch of the target species is often associated with large amounts of unwanted catches (mostly benthic invertebrates), generating high discards and damage to the nets and thus decreasing the economic profitability (Rossetti et al. 2006). Since 1990, an increasing number of fishermen of Viareggio have been using a guarding net applied to the trammel nets. It seems that this device, often built by the fishermen themselves, can significantly reduce unwanted catches while maintaining satisfactory catch rates of the target species. However, to date no scientific evidence is available on the guarding nets' effects on the catch composition of this fishery. The present study used an experimental approach to evaluate the effects of different guarding net devices on catches of target and unwanted species, sorting time and damage to nets in the caramote prawn fishery.

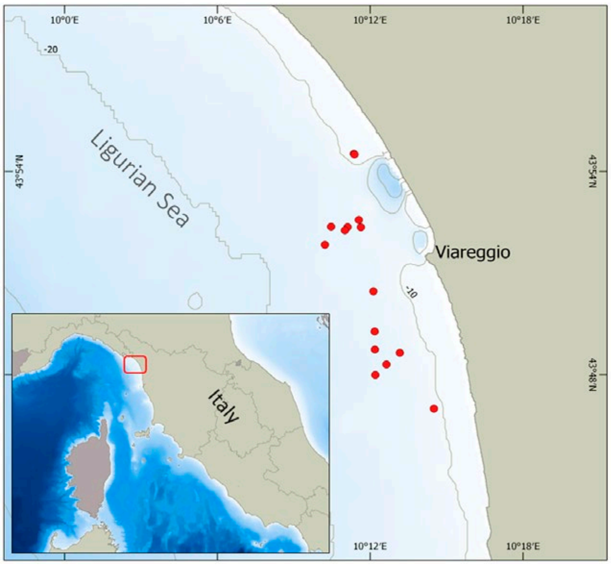

Fig. 1. – Map of the sampling area. Red circles represent the position of the experimental hauls.

MATERIALS AND METHODS

Study area and Viareggio small-scale fishery

The experimental trials were carried out in the southeastern Ligurian Sea. The sampled area, belonging to the fishing grounds of the artisanal fishery of Viareggio, is about 80 km^2 and ranges from 10 to 18 m depth (Fig. 1). It is characterized by sandy bottoms, strongly influenced by fluvial contributions, mainly of the Serchio River, which provides large supplies of organic matter and inorganic particles, in accordance with the temporal variability of the physical-chemical parameters and the water transparency, which is generally low all year round.

Viareggio is, in number of vessels, the most important fishing fleet of the Tuscany Region. According to the official EU data (Fleet Register, http://ec.europa.eu/fisheries/fleet/index.cfm), 106 fishing vessels were registered in 2016 in the Viareggio fishing compartment: of them, 62 belonged to the small-scale fishery. A variety of gears are employed according to the seasonal succession of the target species: the most important are set nets, e.g. different versions of trammel and gill nets. Several fisheries are active during the year, one of them exploiting *P. kerathurus* by trammel nets only from mid-spring to mid-summer.

Interviews with fishermen

At the beginning of the study, before starting the experimental trials, meeting and interviews with the small-scale fishermen of Viareggio were conducted to collect information on fishing capacity (e.g. number and characteristics of the vessels), fishing activity (fishing period, fishing grounds, characteristics of the fishing trips and discards practices) and socio-economic parameters (costs, revenues, employment) of the fishery targeting *P. kerathurus.* The collection of the above information from fishermen continued throughout the study. The technical parameters of the trammel nets used for caramote prawn were recorded by measurement of nets directly at the mooring point. This information was also useful for constructing the nets for the experimental study.

Experimental trials

Sampling gears

The nets employed for the experimental trials were constructed following the characteristics of the nets employed by the fishermen of Viareggio. Three types of trammel net were used (Table 1, Fig. 2): a professional trammel net (STN) used to exploit caramote prawn, without guarding net; and two “experimental” nets, e.g. professional trammel nets provided with a strip of gill net (“guarding net”) placed at the bottom, above the lead line.

Table 1. – Technical features of the gears used for the sampling. STN, Standard Trammel Net; TGN20, standard trammel net provided with a guarding net of 19 mm; TGN25, standard trammel net provided with a guarding net of 24 mm; H, number of meshes (height); N, number of meshes (width); HR, hanging ratio; PA, polyamide; 210/x, nominal titre in deniers; MT, stretched mesh length; h, sheet height; Ul, upper length of panel; Ll, lower length of panel; W, weight of the lead line. For each net a single sheet of the inner and the outer panels is described.

	STN	Ul = 37.5 m	TGN20	Ul = 37.5 m	TGN25	Ul = 37.5 m	
Outer panel	H = 4	N = 250 PA 210/6 ML = 300 mm HR = 0.7	H = 4	N = 250 PA 210/6 ML = 300 mm HR = 0.7	H = 4	N = 250 PA 210/6 ML = 300 mm HR = 0.7	h = 1.20 m
Inner panel	H = 55	N = 2000 PA 210/1 ML = 300 mm HR = 0.45	H = 55	N = 2000 PA 210/1 ML = 300 mm HR = 0.45	H = 55	N = 2000 PA 210/1 ML = 300 mm HR = 0.45	h = 2.640 m
Outer panel	H = 4	N = 250 PA 210/6 ML = 300 mm HR = 0.7	H = 4	N = 250 PA 210/6 ML = 300 mm HR = 0.7	H = 4	N = 250 PA 210/6 ML = 300 mm HR = 0.7	h = 1.20 m
Guarding net			H = 3.5	N = 1250 PA 210/6 HR = 1 ML = 54 mm	H = 3.5	N = 1250 PA 210/6 HR = 1 ML = 54 mm	h = 0.189 (TGN20) h = 0.243 (TGN25)
	Ll = 40.0 m W = 100 g/m		Ll = 40.0 m W = 100 g/m		Ll = 40.0 m W = 100 g/m		

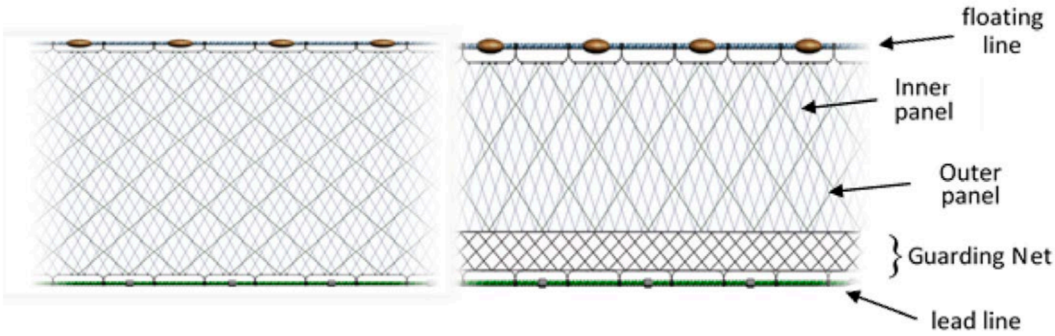

Fig. 2. – Scheme of a standard trammel net (left) and of a trammel net provided with a guarding net (right).

The STN was built with an inner panel of polyamide with stretched meshes of 40 mm and two outer panels in multifilament, with a stretched mesh size of 300 mm. The hanging ratio of the inner panel was 0.45 and that of the outer panels was 0.7. The total height of the net, due to that of the outer panels, was 1.20 m (4 meshes of 300 mm each).

The two experimental trammel nets were built starting from the STN, with which they share the main features. A guarding net, e.g. a monofilament strip with a stretched mesh size of 54 mm, was placed at the bottom of the two nets, just above the lead line. A guarding net of 19 cm height was mounted on the first experimental net (TGN20), and a guarding net of 24 cm height on the second (TGN25). The fishermen of Viareggio who use guarding nets usually apply a strip of gillnet of 50-55 mm mesh size and of 20-25 cm height. In both cases the hanging ratio of the guarding net was 1. The detailed technical characteristics of the three nets are reported in Table 1.

Fishing operations

The experimental trials were carried out using a professional vessel (length overall 11.1 m, gross tonnage 9, engine power 138 hp) belonging to the small-scale fishery fleet of Viareggio, which is usually involved in the caramote prawn fishery. Sampling with the three types of trammel nets was carried out during the peak of the prawn fishing period (in 2016: late spring to early summer) along the coastal area of Viareggio.

In each experimental trial, four net sheets of 100 m length of each type of trammel net (STN, TGN20, TGN25) were used. The 12 sheets of the three nets were tied in a single gang of about 1200 m, leaving an escape area (without nets) of about 1.5 m between adjacent nets to avoid any guiding effect. The sheets' position was changed randomly at each trial to achieve a similar catch probability for each sampling gear.

From June to July 2016, 15 experimental trials were carried out using in each one the 1200 m gang of the three types of nets (Fig. 1). The fishing trials were carried out following the usual procedures of the local fishermen to replicate a standard professional fishing trip: the nets were hauled 1-2 hours before the sunset and retrieved in the early hours of the morning of the following day, for a total of 11-12 hours in the water.

Sorting of the catch

The catch was sorted into commercial and discarded fractions by the fishermen, with no interference from researchers on board. The catch of each experimental trial was classified to the lowest taxonomic level, counted and weighed, according to the three nets used. Totals, in number and weight, were recorded for the catch of each species. Individual size (carapace length, CL, mm) was recorded on all the specimens caught of the target species of the study, *P. kerathurus.* At the end of the experimental trials, the number and size (diameter, in cm) of the areas of net damaged (e.g. pieces of net broken, torn or ripped) was measured for each type of net.

Data analysis

Although the total length of each net employed in this study was the same (400 m), the catches obtained in each trial were standardized to 1000 m of net. With this approach, abundance indices comparable to those available in the scientific literature (Erzini et al. 1997, Prchalová et al. 2011) were obtained.

The species composition of the catch of each net (STN, TGN20, TGN25) was studied taking into account biomass (kg/1000 m) and density (no. of individuals/1000 m) indices, according to the commercial and discarded fraction. Generalized additive models (GAM) (Hastie and Tibshirani 1990) were used to fit log-transformed catch data (biomass indices) and test the effects of the different types of net on the catch of the target species (*P. kerathurus*) and on that of all discards. The Gaussian error distribution (with identity link) was used to fit the data.

The analyses were conducted using the "mgcv" package (Wood 2006) developed in R environment (version 3.2.3, R Core Team 2016). As smoothing terms in the models, two environmental variables were used: the mean depth of each fishing trial and the sea surface temperature (in °C). Sea surface temperature data were downloaded from the Copernicus online database (Copernicus Marine Environment Monitoring Service, http://marine.copernicus.eu).

The best GAM model was selected using a stepwise backward selection approach based on the deviance explained and the Akaike information criterion (AIC, Akaike 1987) to identify the most parsimonious model (lowest AIC) with the greatest explanatory power. The diagnostic of the model was performed by investigating the distribution pattern of the residuals, tested by means of the Shapiro-Wilk test (Shapiro and Wilk 1965), the suggested approach for checking normality in small samples (Razali et al. 2011). Finally, the length-frequency distributions of the catches of *P. kerathurus* obtained with each net were constructed and compared, in pairs, by means of the Kolmogorov-Smirnov test.

RESULTS

Characteristics of the fishery

This paragraph summarizes the information gathered during interviews and meetings held with fishermen of Viareggio. In the study period, 20 small-scale vessels of Viareggio were involved in the caramote prawn fishery. This fleet consisted of vessels of, on average, 8 m length overall and 8 gross tonnage. The usual fishing period ranges from April to July, although fishermen stated that the beginning and the end of the fishing season can vary every year according to the availability of the target species. In 2016 the fishing season lasted from May to July: about 50 fishing days were realized by each vessel, using an average of 2500 m of net per fishing operation.

This fishery, although carried out in a short period of the year, provides an important contribution to the annual economy of each vessel: the target species, *P. kerathurus,* has a high market demand, with a price of about around 30 euro/kg. Fishermen reported that the value of the overall daily catch (6-8 kg of caramote prawn and 3-4 kg of commercial by-catch) is around €200-300; this is mainly due to the target species, as the retained by-catch species, such as the mantis shrimp, make little contribution to the income. The daily costs are limited; fuel cost is approximately only €40 per vessel due to the closeness of the fishing ground.

Fishermen also reported that the catch rates of *P. kerathurus* can vary considerably from one day to another. This species is mostly caught after storms or rough sea events, but unfortunately, in these conditions the presence of unwanted catches is also particularly high. The fishermen reported that a mean of about 5 kg of discard per fishing trip was estimated, although peaks of discards could be 30-40 kg/day/boat. The grey swimming crab, *Liocarcinus vernalis*, was reported as the dominant discarded species in both number and weight. Other species mentioned in the discards were the gastropods *Bolinus brandaris* and *Aporrhais pespelecani,* which, unlike in other Mediterranean areas, have no commercial interest in the Viareggio fishery.

The fishermen mentioned that discards, when abundant, are an important limiting factor for their activity and affect the economic performance of the fishery. In the case of abundant catches of crabs, the "cleaning" operations of the nets are highly time-demanding (they can need up two days), and the help for these operations from additional personnel can be necessary. Moreover, the fishermen declared that the huge presence of crabs can produce holes, rips and other types of damage that reduce the life of the nets. The average duration of a net was reported to be 3-4 months, practically the fishing season for caramote prawn.

For these reasons, for several years an increasing number of fishermen of Viareggio have been using trammels with a guarding net, a device that seems useful to reduce the problems due to unwanted catches.

Experimental trials

Species composition of the catch

During the experimental trials, a total of 60 species belonging to 7 higher taxa (Pisces Osteichthyes and Condrichthyes; Crustacea Decapoda; Mollusca Cephalopoda, Bivalvia and Gastropoda; Echinodermata) were caught: 48 with STN, 35 with TGN20 and 36 with TGN25. The detailed list of the species caught with the catch rates of each species is reported in Table S1 of the Supplementary Material. This table shows differences in the catches of the three nets among species living in different habitats (e.g. benthic, demersal or pelagic). In fact, the catch rates of benthic species were highest in the STN: almost three times those of TGN20 and TGN25. This was particularly evident for species strictly linked to the bottom, such as *L. vernalis* and other crabs such as *Medorippe lanata* and *Macropodia* spp., the gastropods *A. pespelicani*, *B. brandaris* and *Nassarius mutabilis*, the starry ray *Raja asterias*, the thornback ray *R. clavata*, the sand sole *Solea lascaris* and the mantis shrimp *Squilla mantis*.

STN also provided the highest catches for the demersal species (e.g. the common Pandora, *Pagellus erythrinus*), though to a lesser extent than for the benthic species. On the other hand, the catch of the pelagic species (e.g. *E. encrasicolus*, the sardine *S. pilchardus* and the Mediterranean horse mackerel, *Trachurus mediterraneus*) showed no clear differences among the three nets.

Yields of commercial and discarded fractions

Of the 60 species caught, 39 were commercial, while 21 belonged to discards (Table S1 of the Supplementary Material). In spite of the large number of commercial species, the fishermen observed that practically the whole value of the catch was due to the target species, *P. kerathurus*. As regards the retained by-catch, only the mantis shrimp, *S. mantis*, provided a certain contribution to the value of the catch; the other commercial species were caught in small amounts (e.g. the cuttlefish, *Sepia officinalis*) or had very low commercial value because of lack of market interest (e.g. the thinlip mullet, *Liza ramada*) or because of small size or damage (e.g. the anchovy *Engraulis encrasicolus*).

The total biomass caught during the 15 experimental trials accounted for 212.6 kg. The average biomass indices (kg/1000 m of net) of the three nets were: 15.9 for STN, 10.9 for TGN20 and 8.6 for TGN25.

The yields of the three nets also showed differences regarding the composition of commercial and discarded fractions. In biomass, the commercial fraction of STN accounted for 13.8 kg/1000 m of net (87% of the total biomass caught by this gear), that of TGN20 10.2 1 kg/1000 m of net (95%), and that of TGN25 8.9 kg/1000 m of net (96%) (Fig. 3). In density, the commercial fraction of STN accounted for 348.2 ind./1000 m of net (54% of the total numbers caught by this gear), that of TGN20 268.8 ind./1000 m of net (74%), and that of TGN25 258.2 ind./1000 m of net (82%) (Fig. 3). Discards thus accounted for 13% of the biomass caught by STN, 5% of that caught by TGN20 and 4% of that caught by TGN25; and discards accounted for 46% of the individuals caught by STN, 26% of those caught by TGN20 and 18% of those caught by TGN25.

In spite of the large number of the species caught, the catch rates, both in terms of density and biomass, were dominated by a restricted number of species: *P. kerathurus, S. mantis, L. vernalis, E. encrasicolus* and *L. ramada* (Fig. 3, Table S1 Supplementary Material). The target species, *P. kerathurus*, represented from 26% (STN) to 20% (TGN25) of the biomass caught by each net, and from 25% (STN) to 18% (TGN25) of the number of individuals. The mean yields of this species obtained with STN (3.3 kg/1000 m of net; 117.7 ind./1000 m of net) were higher than those of TGN20 (2.1 kg/1000 m of net; 77.2 ind./1000 m of net) and TGN25 (2.2 kg/1000 m of net; 80.5 ind./1000 m of net).

The catches of *L. vernalis,* the dominant species of the discards, were particularly important in terms of number of individuals. Notable differences resulted from the mean density indices of the three types of gear: 258 ind./1000 m of net for STN, 83 ind./1000 m of net for TGN25 and 50.5 ind./1000 m of net for TGN25. This species represented 40% of the total catch in number for STN and from 16% to 23% of that of the two nets provided with a guarding net.

S. mantis was regularly caught in all the experimental trials; also for this species the yields, both in biomass and in number, were higher in STN than in the two trammel nets provided with a guarding net (Fig. 3, Table S1 Supplementary Material).

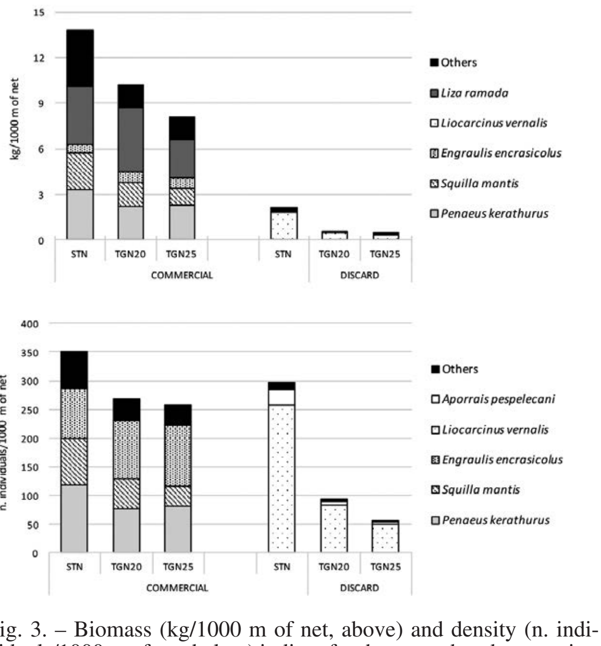

Fig. 3. – Biomass (kg/1000 m of net, above) and density (n. individuals/1000 m of net, below) indices for the most abundant species, according to the type of net and the commercialized and discarded fraction.

Table 2. – GAM for *P. kerathurus* catch rates (biomass index). β_0 is the intercept, s(depth) is a smoothing effect associated with the depth (m), s(SST) is a smoothing effect associated with sea surface temperature, f(net) is the factor net type (STN, TGN20, TGN25), and ε is the error term. AIC, Akaike information criterion; % Deviance, deviance explained. The best model is highlighted in bold.

Model	% Deviance	AIC
β_0 + s(depth) + s(SST) + f(net) + ε	**91.3**	**3.1**
β_0 + s(depth) + s(SST) + ε	85.0	22.6
β_0 + s(SST) + f(net) + ε	75.6	37.4
β_0 + s(depth) + f(net) + ε	22.3	83.5
β_0 + s(depth) + ε	16.9	82.4
β_0 + s(SST) + ε	70.1	42.3
β_0+ f(net) + ε	15.3	87.0

The catches of *E. encrasicolus* were important only in terms of density. For this pelagic species, the yields of TGN25 and TGN20 (104.1 and 101.8 ind./100 m of net, respectively) were slightly higher than those of STN (86.5 ind./1000 m of net). As mentioned before, this species has no commercial value for this fishery, because the specimens caught are of small size or are damaged after the catch.

L. ramada was the species showing the highest biomass indices, but this was due to abundant catches (of large specimens ranging from 250 to 420 g individual weight) recorded only in two hauls. The highest yields of this pelagic and shoaling species were recorded for TGN20.

Analysis of the effects of the three nets on the catch of the target species and of the discard

Table 2 shows the best GAM model, selected according to the stepwise forward methodology, for the biomass indices of *P. kerathurus*. The model has the biomass index of caramote prawn as the dependent variable and sea surface temperature, mean depth and type of net as independent variables. Temperature and depth are smoothers. The variation of the biomass index with the mean depth shows an optimal catch range at 12-15 m; that related to sea surface temperature shows two peaks, at lower and higher temperatures (Fig. 4). The GAM results showed that the biomass indices of *P. kerathurus* of STN were significantly higher than those of TGN20 and TGN25 (Table 3, Fig. 5). On the other hand, the yields of TGN20 and TGN25 net were similar (Fig. 5).

The data complied with the assumptions of homogeneity and independence of variance; the residuals complied with the normality assumptions, following the Shapiro-Wilk test. Finally, the distribution of the residuals was graphically checked with histograms and a qq-plot.

Regarding the analysis of the effects of the three nets on the biomass index of the discards, the best GAM model selected (Table 4) has the biomass index of discarded species as the dependent variable, and sea surface temperature and type of net as independent variables. Sea surface temperature was a smoother; it seems to slightly influence the discarded fraction (Fig. 6).

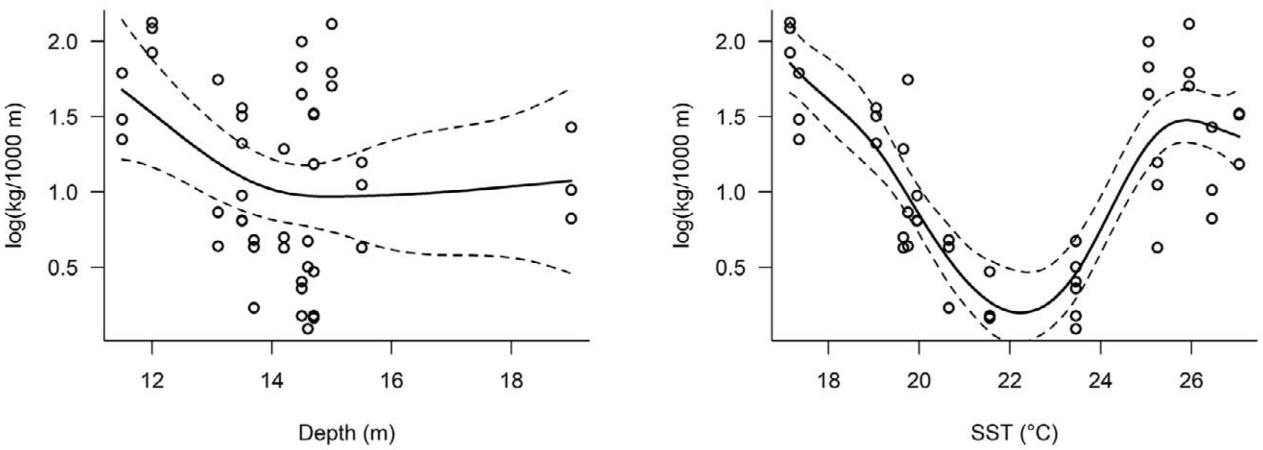

Fig. 4. – Smoothing curves estimated for the mean depth (left) and the sea surface temperature (right) by the GAM model of the biomass index of *P. kerathurus*. Dashed lines represent the 95% confidence intervals.

Table 3. – Summary table of the GAM analysis on the biomass index of *P. kerathurus.*

Factors	Estimate	Parametric coefficients Standard error	t value	p value
Intercept (STN)	1.296	0.055	23.751	<0.001
TGN20	–0.303	0.077	–3.922	<0.001
TGN25	–0.280	0.077	–3.633	<0.001
Smoothing coefficients	**Effective degrees of freedom**	**Reference degrees of freedom**	**F test**	**p value**
s(mean Depth)	4.408	4.897	7.554	<0.001
s(SST)	6.388	7.056	28.825	<0.001

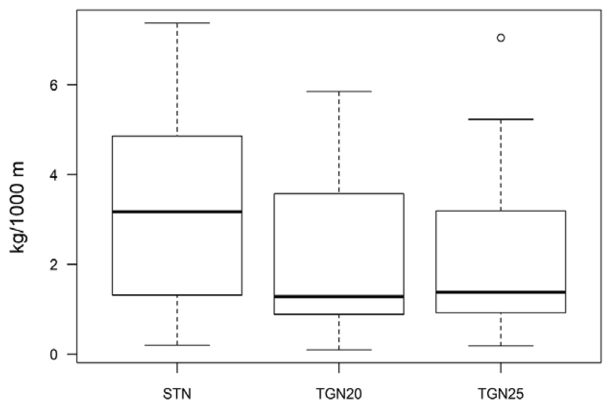

Fig. 5. – Box-plot of the biomass indices (kg/1000 m of net) of *P. kerathurus* for the three types of net. The lower and higher lines of the boxes are the first and the third quantile, respectively; the bold line is the median and the dotted lines delimit the minimum and maximum values excluding outliers.

Table 4. – GAM for discarded species (biomass index). β_0 is the intercept, s(depth) is a smoothing effect associated with the depth (m), s(SST) is a smoothing effect associated with sea surface temperature, f(net) is the factor net type (STN, TGN20, TGN25), and ε is the error term. AIC, Akaike information criterion; % Deviance, deviance explained. The best model is highlighted in bold.

Model	% Deviance	AIC
β_0 + s(depth) + s(SST) + f(net) + ε	76.3	33.8
β_0 + s(depth) + s(SST) + ε	42.3	67.8
β_0 + s(SST) + f(net) + ε	**76.7**	**31.9**
β_0 + s(depth) + f(net) + ε	34.5	68.5
β_0 + s(depth) + ε	20.3	67.0
β_0 + s(SST) + ε	41.8	81.9
β_0+ f(net) + ε	32.5	67.2

The GAM results show that the biomass indices of the overall discard obtained with STN are significantly higher than those obtained with TGN20 and TGN25 (Table 5, Fig. 7). The discard yields obtained with TG20 and TGN25 net were, on the other hand, very similar (Fig. 7). The data complied with the assumptions of homogeneity and independence of variance; the residuals complied with the normality assumptions, following the Shapiro-Wilk test. Finally, the distribution of the residuals was graphically checked with histograms and a qq-plot.

In summary, the results of the experimental trials show that the presence of the guarding net in the standard trammel significantly reduces the catches of discard: by about 70% for the TGN20 and by about 80% for the TGN25.

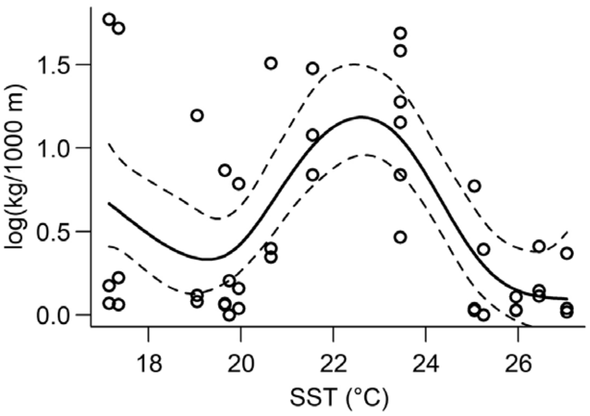

Fig. 6. – Smoothing curves estimated for the Sea Surface Temperature of the GAM model of the biomass index of the discarded species. Dashed lines represent the 95% confidence intervals.

Table 5. – Summary table of the GAM analysis on the biomass index of the discarded species.

Factors	Parametric coefficients Estimate	Standard error	t value	p value
Intercept (STN)	0.961	0.079	12.122	<0.001
TGN20	–0.651	0.112	–5.80	<0.001
TGN25	–0.718	0.112	–6.40	<0.001
Smoothing coefficients	Effective degrees of freedom	Reference degrees of freedom	F test	p value
s(SST)	5.518	6.512	9.631	<0.001

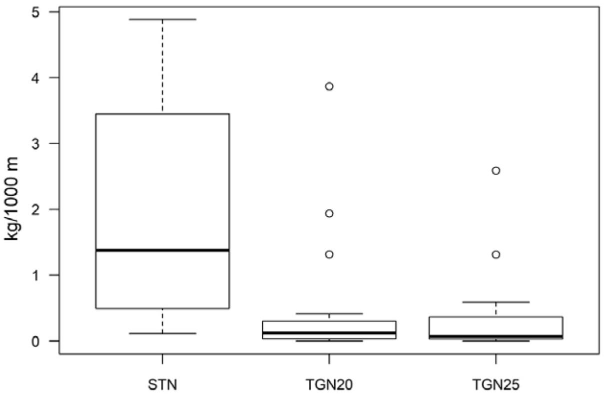

Fig. 7. – Box-plot of the biomass indices (kg/1000 m of net) of the discarded species for the three nets. The lower and higher lines of the boxes are the first and the third quantile, respectively; the bold line is the median and the dotted lines delimit the minimum and maximum values excluding outliers.

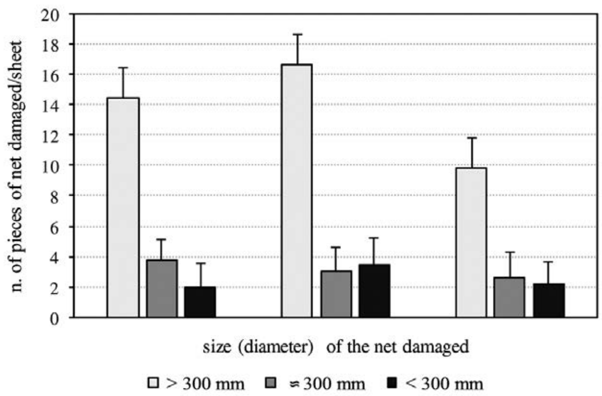

Fig. 9. – Number of pieces of net damaged (average value per sheet of net), according to the three types of net. Data were recorded at the end of the experimental trials.

During the study, a total of 1652 individuals of *P. kerathurus* were caught, ranging from 19 to 54 mm CL. The size structure of the specimens caught with the three nets was very similar (Fig. 8); no significant differences were detected with the Kolmogorov-Smirnov test (STN vs TGN20, D=0.033, χ^2=0.223, n.s; STN vs TGN25, D=0.07, χ^2=0.99, n.s; TGN20 vs TGN25, D=0.061, χ^2=0.742, n.s). Two modes were present: one, the principal, at 33 mm CL, the other at 42 mm CL.

Figure 9 reports the various types of damage (e.g. pieces of net broken, torn or ripped) detected in the three nets at the conclusion of the experimental trials. The number of damages observed in the STN was about three times higher than that recorded in TGN20 and TGN25. A Kruskall Wallis non-parametric ANOVA showed significant differences ($p<0.05$) among the three nets.

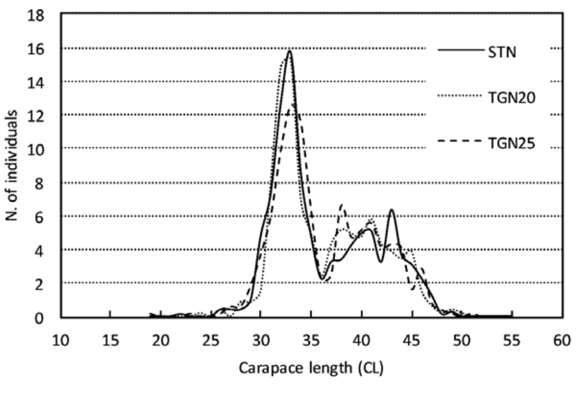

Fig. 8. – Length frequency distribution of the specimens of *P. kerathurus* caught with the three types of net.

DISCUSSION

Small-scale fishing (SSF) is the most important sector for marine fisheries in the Mediterranean, as regards number of vessels and personnel involved (FAO 2016). SSF employs small vessels with little mechanization, essentially operating in the coastal areas and generating an activity strictly linked to the territory (Guyader et al. 2013). The gears most used are set gears such as trammel nets, gillnets, traps and longlines (Tzanatos et al. 2006, Maynou et al. 2011). Italy is the country where SSF provides the highest landings in the Mediterranean (FAO 2016), with a fleet of about 7500 vessels and 13000 fishermen (STECF 2016).

Although discard rates of SSF are much lower than those of other fisheries (e.g. trawling), the total amount of discards produced should not be neglected if we consider the large number of vessels belonging to this sector. Moreover, the fact that the SSF fishing effort is mainly concentrated in the coastal areas is another factor that should call attention to the impacts of these fisheries. This aspect is particularly important for the Mediterranean SSF, whose activity is often carried out on ecologically important and sensitive habitats (e.g. sea grass meadows, coralligenous banks and rocky bottoms) and in areas subjected to fishing regulation (e.g MPAs) (Maynou et al. 2011).

Therefore, in particular in Mediterranean, it is important to minimize the unwanted catches of SSF, applying innovative technical solutions and adopting proper management measures.

The results of the present study have provided scientific evidence that the guarding net used by several fishermen of the caramote prawn fishery of Viareggio is effective for reducing the problems arising from unwanted catches (mostly benthic species, such as crabs and gastropods). According to the results of the 15 experimental trials, when a guarding net is applied to an STN, a decrease about 75% of the discarded biomass can be obtained. To reduce the variability and the uncertainty of the estimates obtained, this study should be continued, increasing the sample size and replicating the experiment in other fishing seasons.

The present results agree closely with those of a similar study performed by Metin et al. (2009) for the caramote prawn fishery in Turkey. The effectiveness of the guarding net for decreasing the unwanted catches was also reported by Sartor et al. (2006, 2007), Aydin et al. (2013) and Gökçe et al. (2016) for other Mediterranean trammel net fisheries.

In practical terms, the guarding net acts by increasing the escape probability of the species living in contact with or just above the bottom. This action affects mainly the benthic invertebrates, belonging both to discards (crabs, gastropods and holothurians) and to the commercial fraction (mantis shrimps and cuttlefish). A significant reduction was also observed in the catches of the target species of the investigated fishery, the caramote prawn, but of a lesser extent, as this species is less strictly linked to the bottom (Bolognini 2017).

The guarding net does not substantially change the yields of demersal or nectobenthic species, as was previously demonstrated by Sartor et al. (2006) for the striped sea bream, *Lithognatus mormyrus* and the common Pandora, *Pagellus erythrinus.*

In the present study, discards were dominated by the grey swimming crab, *L. vernalis*. the presence of this species in the discards of trammel nets employed on coastal sandy bottoms has been widely documented (Rossetti et al. 2006, Grati et al. 2015, Pranovi et al. 2016). The grey swimming crab is an important faunistic element of the species assemblages of the shallower coastal bottoms; its catchability is highly variable, being influenced by factors such as sea conditions, water transparency and the current regime. Sartor et al. (2006) reported about 1600 specimens caught in a single 500-m trammel net fishing operation.

In the benthic and demersal ecosystems, *L. vernalis* is an important food resource for many coastal fishes, such as Scorpaenids (Relini et al. 2002) and Sparids (Fabi et al. 2006). Alves et al. (2006) also observed that the grey swimming crab is a key prey for the common cuttlefish, *S. officinalis*. This cephalopod is abundant in the area investigated by the present study, particularly in winter, when it approaches the coast for reproduction (Silvestri et al. 2003). Therefore, a high fishing mortality of *L. vernalis* can produce cascading effects on the various species that depend on this trophic resource.

As mentioned before, the large amount of discards is an important limiting factor for this fishery, because it produces costs at different levels: the time and labour for cleaning the nets, the needs to replace or repair the nets, and the loss of fishing days. The soft and thin filaments of the trammel nets for caramote prawn make them particularly susceptible to being cut and broken by chelae and mandibles of crabs or by the shells of gastropods and bivalves.

The present results suggest that a systematic use of the guarding net by the caramote prawn fishery of Viareggio can produce environmental and economic benefits. According to the information collected from the interviews with fishermen, we can roughly estimate that the wide use of the guarding net by the vessels of Viareggio fleet exploiting *P. kerathurus* can lead to a reduction of about 4.5 t of discards per year (considering 5 kilos discarded per day, 1200 total fishing days and about 75% reduction of discard due to the guarding net).

This device is relatively inexpensive (the cost of trammel with a guarding net is more or less the same as that of STN). The economic loss due to the reduction of catches of target species and commercial by-catch can be compensated by the reduction of costs due to sorting time, labour and material. In general, the use of trammel nets provided with a guarding net could be envisaged in areas where the unwanted catches of benthic species constitute a problem not only for the environment but also for the fishermen, and also in areas where fishing activity is regulated, e.g. marine protected or sensitive areas.

The results of the present study underpin the guarding net as a technical device that could be adopted in professional trammel net fisheries. However, the fishermen should be involved in the process: recent experiences of small-scale fisheries co-management in Mediterranean show the importance of their contribution to a sustainable use of the resources (Lleonart et al. 2014).

ACKNOWLEDGEMENTS

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SUPPLEMENTARY MATERIAL

The following supplementary material is available through the online version of this article and at the following link:
http://scimar.icm.csic.es/scimar/supplm/sm04765esm.pdf

Table S1. – Taxonomic list of the species caught, with density and biomass indices according to the three types of net. STN, standard trammel net; TGN20, standard trammel net with guarding net of 19 cm; TGN25, standard trammel net with guarding net of 24 cm. Cat, commercial category (C, commercial; NC, non commercial; H, habitat; B, benthic; D, demersal or nektobenthic; P, pelagic).

Discards regulation vs Mediterranean fisheries sustainability
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Reducing unwanted catches of trammel nets: experimental results of the "guarding net" in the caramote prawn, *Penaeus kerathurus*, small-scale fishery of the Ligurian Sea (western Mediterranean)

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Supplementary material

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			STN				TGN20				TGN25			
	Cat	H	n/1000 m		kg/1000 m		n/1000 m		kg/1000 m		n/1000 m		kg/1000 m	
Taxa			mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
CRUSTACEA			**459.5**	**247.092**	**7.475**	**3.006**	**212.333**	**174.692**	**4.260**	**1.898**	**168.667**	**110.691**	**3.732**	**1.930**
Inachus sp.	NC	B									0.167	0.645	<0.001	0.001
Inachus thoracicus	NC	B	0.167	0.645	0.001	0.002	0.167	0.645	0.001	0.002				
Liocarcinus vernalis	NC	B	258.333	249.304	1.751	1.583	83.167	172.255	0.502	0.978	50.500	96.266	0.333	0.621
Macropipus tuberculatus	NC	B	0.167	0.645	0.002	0.006								
Macropodia longipes	NC	B									0.333	1.291	0.001	0.003
Macropodia longirostris	NC	B	0.167	0.645	0.001	0.003								
Macropodia sp.	NC	B	0.167	0.645										
Penaeus kerathurus	**C**	**D**	**117.667**	**85.322**	**3.326**	**2.406**	**77.167**	**64.065**	**2.159**	**1.834**	**80.500**	**75.055**	**2.267**	**2.034**
Medorippe lanata	NC	B	0.333	0.880	0.004	0.010	0.167	0.645	0.002	0.006	0.333	1.291	0.002	0.009
Squilla mantis	C	B	82.333	60.433	2.392	1.836	51.667	43.902	1.597	1.323	36.833	39.905	1.130	1.113
Upogebia sp.	NC	B	0.167	0.645	0.001	0.003								
ECHINODERMATA			**0.500**	**1.402**	**0.002**	**0.006**	**0.167**	**0.645**	**<0.001**	**0.001**	**0.167**	**0.645**	**<0.001**	**0.001**
Astropecten irregularis	NC	B	0.500	1.402	0.002	0.006								
Oestergrenia digitata	NC	B					0.167	0.645	<0.001	0.001				
Ophiuroidea indet.	NC	B									0.167	0.645	<0.001	0.001
BIVALVIA			**0.167**	**0.645**	**0.001**	**0.004**								
Anadara demiri	NC	B	0.167	0.645	0.001	0.004								
GASTROPODA			**29.0**	**37.2**	**0.166**	**0.213**	**8500**	**12.291**	**0.047**	**0.106**	**3.833**	**10.643**	**0.033**	**0.091**
Aporrhais pespelecani	NC	B	25.500	36.818	0.118	0.181	7.500	18.540	0.037	0.090	3.000	8.139	0.015	0.039
Bolinus brandaris	NC	B	1.500	1.842	0.045	0.059	0.500	1.035	0.009	0.019	0.833	2.616	0.019	0.052
Nassarius mutabilis	NC	B	2.000	3.919	0.004	0.007	0.500	1.035	0.001	0.002				
CEPHALOPODA			**2.000**	**2.155**	**0.374**	**0.440**	**0.667**	**1.484**	**0.123**	**0.293**	**1.333**	**2.289**	**0.317**	**0.495**
Sepia officinalis	C	B	2.000	2.155	0.374	0.440	0.667	1.484	0.123	0.293	1.333	2.289	0.317	0.495
CONDRICHTHYES			**3.167**	**5.936**	**0.516**	**1.469**	**0.333**	**0.880**	**0.120**	**0.438**	**0.167**	**0.645**	**0.008**	**0.030**
Raja asterias	C	B	1.500	3.873	0.516	1.469	0.333	0.880	0.120	0.438				
Raja clavata	C	B	0.500	1.936	0.467	1.809								
Raja polystigma	C	B	0.333	1.291	0.028	0.107					0.167	0.645	0.008	0.030
Torpedo torpedo	C	B	0.833	2.041	0.120	0.330								
OSTEICHTHYES			**150.5**	**219.2**	**6.786**	**12.977**	**140.2**	**251.2**	**6.351**	**14.777**	**140.3**	**241.4**	**4.509**	**10.576**
Alosa fallax nilotica	C	P	0.167	0.645	0.012	0.046	0.167	0.645	0.028	0.108	0.167	0.645	0.017	0.066
Arnoglossus laterna	NC	B	3.333	4.970	0.100	0.282	0.667	1.759	0.008	0.022	0.833	2.616	0.011	0.036
Boops boops	C	P							0.167	0.645	0.022	0.083	0.000	0.000
Buglossidium luteum	NC	B	0.022	0.084	<0.001	<0.001					0.022	0.084	<0.001	<0.001
Chelidonichthys obscurus	C	B	0.167	0.645	0.001	0.003								
Chelydonicthys lucerna	C	B	11.667	26.854	0.207	0.306	7.667	18.909	0.125	0.212	8.167	20.734	0.124	0.237
Conger conger	C	B	0.167	0.645	0.011	0.041								
Deltentosteus quadrimaculatus	NC	B	0.167	0.154	0.001	0.005								
Diplodus annularis	C	D	5.833	9.386	0.206	0.326	3.167	6.779	0.103	0.238	3.833	6.041	0.128	0.193
Engraulis encrasicolus	C	P	86.500	141.219	0.578	0.960	101.833	184.610	0.697	1.279	104.167	178.362	0.679	1.157
Gobius geniporus	NC	B					0.167	0.645	0.001	0.005				
*Gobius nige*r	C	B	0.833	1.543	0.013	0.023								
Hippocampus hippocampus	NC	B	0.167	0.645	0.001	0.003								
Liza aurata	C	P					0.167	0.645	0.054	0.210				
Liza ramada	C	P	9.500	26.863	3.807	10.330	10.167	31.530	4.154	12.387	6.500	22.456	2.450	8.243
Merluccius merluccius	C	D					0.500	1.402	0.005	0.014	0.167	0.645	0.003	0.010
Mullus barbatus	C	D	0.333	0.880	0.015	0.040					0.167	0.645	0.003	0.012
Oblada melanura	C	P					0.167	0.645	0.009	0.035				
Pagellus acarne	C	D	0.167	0.645	0.001	0.003					0.333	0.880	0.009	0.033
Pagellus erythrinus	C	D	1.167	2.814	0.087	0.209	0.333	1.291	0.029	0.114	0.500	1.035	0.033	0.070
Pomatomus saltatrix	C	P									0.333	0.880	0.045	0.134
Sardina pilchardus	C	P	2.000	3.684	0.018	0.028	1.500	3.987	0.014	0.044	2.667	4.674	0.030	0.053
Sardinella aurita	C	P	3.833	8.705	0.150	0.355	3.000	8.409	0.110	0.333	2.333	6.578	0.081	0.242
Sciaena umbra	C	D	0.167	0.645	0.012	0.046					0.167	0.645	0.034	0.133
Scomber scombrus	C	P	0.167	0.645	0.013	0.050	0.333	0.880	0.033	0.086	0.167	0.645	0.017	0.066
*Scorpaena porcu*s	C	B					0.167	0.645	0.003	0.010				
Solea lascaris	C	B	9.667	14.232	0.357	0.527	2.000	4.140	0.079	0.159	2.167	4.212	0.092	0.196
Solea solea	C	B	1.167	3.255	0.032	0.102	0.167	0.645	0.007	0.028	0.333	0.880	0.019	0.049
Sphyraena sphyraena	C	P	0.500	1.402	0.112	0.321	0.667	1.484	0.116	0.251	0.167	0.645	0.054	0.208
Spicara flexuosa	C	P	0.833	1.809	0.055	0.122	0.500	1.035	0.029	0.060	0.333	1.291	0.018	0.071
Spicara maena	C	P	0.167	0.645	0.009	0.036					0.167	0.645	0.012	0.047
Spondyliosoma cantharus	C	D	0.167	0.645	0.004	0.015								
Stromateus fiatola	C	P	0.333	1.291	0.089	0.343	0.333	0.880	0.072	0.191	0.167	0.645	0.086	0.334
Trachurus mediterraneus	C	P	5.500	16.669	0.447	1.222	4.333	10.916	0.336	0.715	4.167	12.125	0.259	0.766
Trachurus trachurus	C	P	0.167	0.645	0.035	0.137	0.833	2.616	0.157	0.553				
Trachynotus ovatus	C	P					0.167	0.645	0.016	0.062	0.167	0.645	0.003	0.011
Umbrina cirrosa	C	D	3.000	5.106	0.393	0.714	1.167	2.650	0.164	0.411	2.000	3.162	0.281	0.517
Total overall			**644.833**	**404.894**	**15.934**	**13.966**	**362.167**	**313.945**	**10.900**	**15.1728**	**314.500**	**277.789**	**8.599**	**11.033**
Number of species			**48**				**35**				**36**			