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The use of a square mesh codend and sorting grids to reduce catches of young fish and improve sustainability in a multispecies bottom trawl fishery in the Mediterranean

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SUMMARY: In order to improve the capacity of bottom trawl fishing gears to reduce catches of young fish and discards in a highly exploited demersal trawl fisheries in the Mediterranean, the size-selection performance of a 36-mm square-mesh codend and two sorting grids with 20 and 15 mm bar spacing was assessed. Alternate hauls were used to assess the selectivity of 36-mm square-mesh codend. Selectivity of sorting grids was assessed using a double codend in which fish that escaped through the grid were captured in the lower codend while other fish were guided into the upper codend. The mean selection length (L_{50}) for European hake was 18.5 cm and that for the Atlantic horse mackerel was 14.0 cm with the 36-mm square-mesh codend. These values are close to their current minimum landing sizes (20 cm for hake and 12 cm for horse mackerel). The sorting grid with 20-mm bar spacing showed L_{50} value of 13.3 cm for hake, suggesting that a larger grid-spacing would be needed to obtain sufficient sorting performance. Similarly, for Atlantic mackerel the estimated L_{50} of 14.3 cm indicates that larger grid spacing is required to attain an L_{50} that would be close to the current MLS (18 cm). For Atlantic horse mackerel and red mullet, the L_{50} obtained with the sorting grid with 20-mm bar spacing was close to the MLS of these species (the MLS of red mullet is 11 cm). The selectivity of the sorting grid with 15-mm bar spacing was generally very poor. Size-selection performance of sorting grids was assessed for the first time in the local fisheries. In order to effectively improve size-selection, seasonal and depth-dependent differences between target and by-catch species must be taken into account, which is a good indicator of the difficulty of implementing a single mesh size or grid spacing in the Mediterranean demersal trawl fishery.

Keywords: Mediterranean Sea, sorting grid, square mesh, selectivity, multispecies fishery, bottom trawl, European hake, Atlantic horse mackerel, Atlantic mackerel, red mullet.

RESUMEN: EL USO DE COPO DE MALLA CUADRADA Y REJILLAS SEPARADORAS PARA REDUCIR LAS CAPTURAS DE PECES JUVENILES Y MEJORAR LA SOSTENIBILIDAD DE UNA PESQUERÍA MULTIESPECÍFICA DE ARRASTRE DE FONDO EN EL MEDITERRÁNEO. – Con el propósito de mejorar la capacidad de las redes de arrastre de fondo para reducir las capturas de peces juveniles y descartes en una pesquería multispecífica altamente explotada en el Mar Mediterráneo, se evaluó la selectividad de las tallas de diversas especies demersales mediante el uso de una malla cuadrada de 36 mm y dos rejillas con separación entre barras de 20 y 15 mm. Se usó el método de lances alternativos para evaluar la selectividad del copo de malla cuadrada. La selectividad de las rejillas se evaluó mediante un doble copo. Los peces que escaparon de la rejilla se capturaron en el copo inferior y el resto del pescado se guió y capturó en el copo superior. Con el copo de malla cuadrada, la talla media de madurez (L_{50}) de la merluza y el jurel fue respectivamente de 18,5 cm y 14,0 cm. Estos valores se aproximan a la talla mínima de selección (MLS para la merluza es de 20 cm y para la jurel es de 12 cm). Con la rejilla con separación entre barras de 20 mm, la L_{50} de la merluza fue de 13,3 cm, lo cual sugiere que sería conveniente aumentar la separación entre barras para obtener una L_{50} más próxima a la MLS. La caballa se seleccionó con una L_{50} de 14,3, por debajo de la MLS de 18 cm. El jurel y el salmonete mostraron L_{50} cercana a la MLS (MLS del salmonete es 11 cm). La rejilla con espacios de 15 mm fue muy poco selectiva. Este es el primer trabajo que se realiza en el área en el que se compara el funcionamiento de la malla cuadrada y las rejillas separadoras. La tecnología de las rejillas separadoras se aplicó por primera vez con el objetivo de mejorar la explotación de las pesquerías locales. La mejora en la selección de tallas requiere tener en cuenta la variación estacional y en profundidad de las especies objetivo y especies acompañantes, lo que demuestra la dificultad de implementar una sola malla o rejilla en toda la pesquería demersal de arrastre del Mediterráneo.

Palabras clave: Mar Mediterráneo, rejilla separadora, malla cuadrada, selectividad, pesquería multispecífica, arrastre de fondo, merluza, jurel, caballa, salmonete.

INTRODUCTION

Fishing pressure generated by the multispecies trawl fishery in the Mediterranean Sea has increased during the last two decades and many commercial species are now overexploited. An indication of this is the high share of juvenile fish in the catches (Larrañeta *et al.*, 1969; Stergiou *et al.*, 1997; Leonart, 2001; Sánchez *et al.*, 2004). Poor selectivity of bottom trawls using the legislated 40-mm diamond mesh codend greatly contributes to the unfavourable catch composition and relatively high discard rates (Martín *et al.*, 2001; Sánchez *et al.*, 2004). Total discards in the western Mediterranean bottom trawl fishery range from 17 to 34% of the total catch weight (Sánchez *et al.*, 2004). It is worth noting that in Mediterranean fishery, a fraction of undersized fish are not discarded but marketed.

More than 300 benthic and epibenthic species have been reported in the catches of the commercial trawler fleet targeting European hake (*Merluccius merluccius*) in the western Mediterranean (Martín *et al.*, 2001). The percentage of hake below the minimum landing size (current MLS is 20 cm) caught and discarded is highly variable: it depends, among other factors, on the fishing ground and season, and may be up to 64% (in numbers) of the total hake catch (Martín *et al.*, 2001; Sánchez *et al.*, 2004). Furthermore, many other commercially important species caught in large quantities are undersized and immature, mainly due to the use of a 40 mm diamond-shaped mesh that is poorly selective, preventing the small individuals from escaping the nets (e.g. Sardà *et al.*, 2004).

It has been well demonstrated that by-catch and discards can be reduced in trawl fishery, for instance, by using a square mesh codend or a sorting grid (Madsen and Hansen, 2001; Polet, 2002; Valdemarsen and Suuronen, 2003). Few studies, however, have assessed the performance of these techniques in the highly multispecies trawl fishery of the Mediterranean Sea (Steward, 2002). Early selectivity experiments carried out off the Ebro River delta (NW Mediterranean) examined the selectivity of various diamond-mesh codends (Larrañeta *et al.*, 1969). Recently, the selectivity of a 40-mm square mesh codend was tested in the deepwater (>500 m) crustacean trawl fishery off the Balearic Islands in the western Mediterranean (Guijarro and Massutí, 2006). Preliminary and experimental selectivity trials using a sorting grid

(with 20-mm bar spacing) to reduce undersize hake in trawl catches produced promising results, allowing roughly 50% of undersized hake to escape (Sardà *et al.*, 2005; Sardà *et al.*, 2004).

To reduce catches of young fish and improve sustainability of bottom trawl fisheries in the Iberian Mediterranean, trials with a square-mesh codend and a codend equipped with sorting grid were conducted. These trials were expected to increase our knowledge on the selectivity performance of these new sorting techniques in the Mediterranean multispecies conditions, and to provide solutions that are acceptable for the fishing industry. Selectivity parameters are used to assess and compare the performance and impacts of these techniques.

METHODS

Field experiments

The experiments were performed on board the commercial trawler “Germans Fèlix” (18.3 m, 440 HP) at a mean depth of 73 m (between 45 and 93 m) in June and 38 m (between 20 and 55 m) in September 2003 (Fig. 1) off the Ebro River delta (St. Carles de la Ràpita, Spanish coast, NW Mediterranean). In the June trials, a 36-mm stretch square-mesh codend (SM36) and two sorting grids with a bar spacing of 15 mm (BS15) and 20 mm

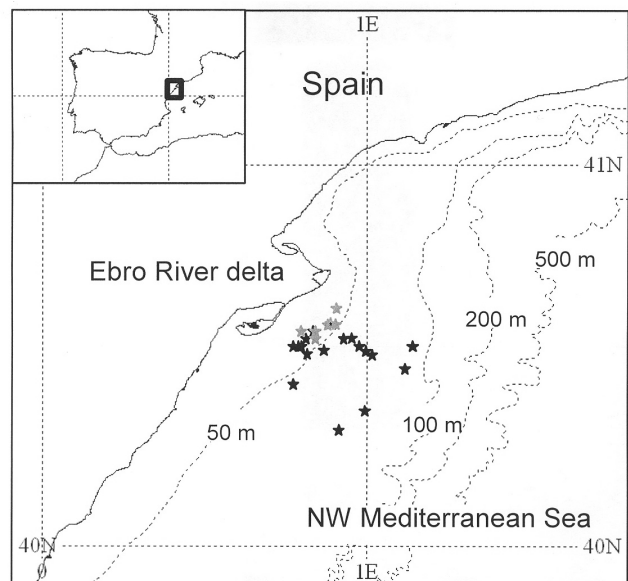


FIG. 1. – The study area showing the start-points of the experimental trawl tows. Black stars are tows carried out in June 2003 and grey stars are tows carried out in September 2003.

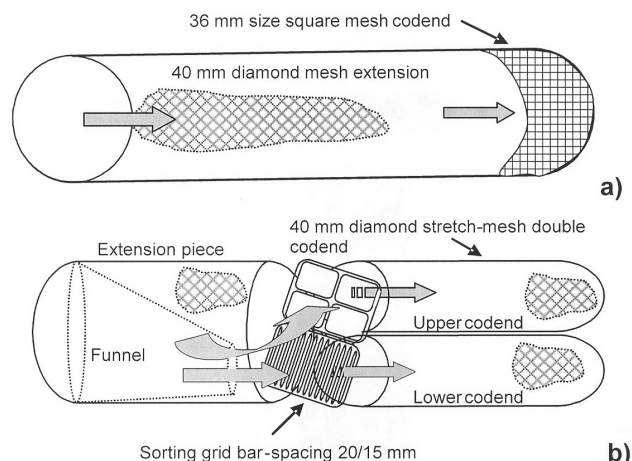


FIG. 2. – Schematic drawings of (a) the square mesh codend and (b) the sorting grids (frame 100 x 145 cm) tested in this study. The lower section of the grid allowed small individuals to escape through the bars to a lower codend, while the grid guided larger fish into the upper codend (representing the catch).

(BS20) were tested. In the September trials, only the 20-mm sorting grid was tested (BS15 was not included because of the poor selectivity observed in June).

The 36-mm square mesh codend was made of non-knotted braided polyethylene (PE) netting (twine diameter 3 mm) and was ca 3 m long (Fig. 2a). It was attached to the codend extension made of 40 mm diamond mesh (in circumference, the square mesh codend had half the meshes of the extension). The sorting grids (BS20 and BS15) were made of rigid plastic, and consisted of two hinged sections, one open and one with a grid. These sections were hinged together and fitted at the end of a standard 40-mm diamond mesh extension piece (Fig. 2b). The only technical difference between the two sorting grids was the spacing between the bars. Selective performance of sorting grids was assessed using a double codend method by which grid-escapes were captured in the lower codend and those fish that were not sorted through the grid were guided by it into the upper codend (representing the catch) (Fig.

2b). The collection codends were made of 40-mm diamond stretch mesh PE netting (twine, diameter 5 mm). The guiding funnel in front of the grid guided the fish towards the lower part of the grid (Fig. 2b).

An alternate haul method was used to assess the selectivity of the SM36 codend. This method was chosen instead of the codend-cover method, in order to prevent possible disturbances of the cover on the filtering of the two codends. The control was a standard 40-mm stretch knotted diamond-mesh codend (DM40; PE twine diameter 5 mm), which shows negligible selection in the fish length range of interest.

In total, 18 tows were carried out in June and 7 in September (Table 1). Six hauls were conducted in the alternate haul trials, three with both codends (SM36 and DM40). Mean tow duration was 60 min and mean towing speed 3.7 knots. Rigging and overall performance of the experimental trawl (e.g. door spread, mouth opening) during towing was monitored using Scanmar acoustic sensors.

Catch sampling was focussed on the fishing grounds in which most abundant commercial species occur: European hake, Atlantic horse mackerel (*Trachurus trachurus*), poor cod (*Trisopterus minutus capelanus*), red mullet (*Mullus barbatus*), Atlantic mackerel (*Scomber scombrus*), spotted flounder (*Citharus linguatula*), and gurnards (Triglidae). Individual species were measured to the nearest 0.1 cm total length (TL), and total catch per species was weighted (± 1 kg).

Data analyses

The SELECT (Share Each Length's Catch Total) model (Millar, 1992) was used to fit data to logistic and Richard's functions. For the square mesh experiment, the probability that a fish of length l entering the gear will be retained by the net was assumed to be $r(l) = p \exp(a+bl) / [1-p + \exp(a+bl)]$. The values of the parameters p , a ,

TABLE 1. – Date, number of hauls and mean trawling depth.

Sorting device/codend	Date	Number of hauls	Trawling depth (m)
Sorting grid with 15-mm bar spacing (BS15)	11-12 Jun 2003	6	67
Sorting grid with 20-mm bar spacing (BS20)	17-18 Jun 2003	6	75
Sorting grid with 20-mm bar spacing (BS20)	18-19 Sep 2002	7	38
40-mm diamond mesh codend (DM40)	10-Jun-03	3	73
36-mm square-mesh codend (SM36)	20-Jun-03	3	74

TABLE 2. – Best fitting selectivity models and parameter (a , b , p and δ) values with standard errors (SE) indicated.

Sorting device	Survey month	Model	Catch in number	No of valid hauls	a	(SE)	b	(SE)	p, δ	(SE)
<i>Merluccius merluccius</i> , European hake										
SM36	Jun	Logistic	920	6	-8	0.53	0.43	0.05	$p = 0.83$	0.05
BS20	Jun	Logistic	2087	6	-7.9	0.57	0.60	0.04		
BS20	Sep	Logistic	844	3	-12.5	1.96	0.93	0.12		
BS15	Jun	Logistic	2650	6	-2.6	0.37	0.50	0.04		
<i>Trachurus trachurus</i> , Atlantic horse mackerel										
SM36	Jun	Logistic	355	4	-12.42	3.21	0.89	0.26	$p = 0.63$	0.05
BS20	Jun	Logistic	220	5	-6.39	1.26	0.48	0.07		
BS20	Sep	Logistic	549	7	-8.67	1.37	0.66	0.10		
BS15	Jun	Logistic	1059	6	-15.66	2.00	1.29	0.17		
<i>Trisopterus minutus capelanus</i> , Poor cod										
SM36	Jun	Logistic	190	4	-9.02	3.32	0.51	0.36	$p = 0.9$	0.19
BS20	Jun	Logistic	314	4	-11	1.79	0.70	0.12		
BS15	Jun	Logistic	316	5	-8.92	1.06	1.01	0.12		
<i>Mullus barbatus</i> , Red mullet										
BS20	Sep	Logistic	4242	6	-7.14	0.63	0.47	0.05		
<i>Scomber scombrus</i> , Atlantic mackerel										
BS20	Jun	Logistic	340	6	-5.15	1.89	0.38	0.10		
<i>Citharus linguatula</i> , Spotted flounder										
SM36	Jun	Logistic	544	6	-6.62	6.05	0.71	0.62	$p = 0.5$	0.04
BS20	Jun	Logistic	341	6	-6.5	0.85	0.52	0.07		
BS20	Sep	Logistic	356	5	-5.19	1.37	0.58	0.11		
BS15	Jun	Logistic	630	6	-5.51	0.64	0.61	0.06		
Triglidae, Gurnards										
SM36	Jun	Logistic	404	6	-12	1.80	0.95	0.20	$p = 0.7$	0.11
BS20	Jun	Richard's	326	3	-5.5	0.07	0.55	0.01	$\delta = 1.1$	0.01

and b were estimated by maximizing the log-likelihood function (Tokai, 1997). The parameter p represents here the fishing intensity (Millar and Fryer, 1999). Parameters a and b were used to calculate the 50% selection length, $L_{50} = -a/b$, and the selection range, $SR = 2\ln(3)/b$. The best model fits (Table 2) were found by testing the hypotheses $H_0: p = 0.5$ (equal split) and $H_1: p \neq 0.5$ (estimated split) using Pearson's chi-square statistic. For the sorting grid experiment, the equation used to calculate the best parameter values for the experimental sorting grids was based on $r(l) = \exp(a + bl) / [1 + \exp(a + bl)]^{1/\delta}$. The value of δ is a measure of the asymmetry of the selection curve around L_{50} . The best fitting models (Table 2) were found by testing the hypotheses $H_0: \delta = 1$ for the logistic curve, and $H_1: \delta \neq 1$ for the Richard's curve using Pearson's chi-square statistic. Deviance residuals and parameter errors indicated significant inter-haul variability, so an appropriate adjustment was made to correct the over-dispersion in the standard errors for the selection parameters and residual deviances (Wileman *et al.*, 1996).

RESULTS

Merluccius merluccius: The 36-mm square mesh codend produced for hake an L_{50} of 18.5 cm and selection range (SR) of 5.1 cm (Table 3). The 20-mm sorting grid, on the other hand, produced for *M. merluccius* an L_{50} of only 13.1 cm in June and 13.5 cm in September. The selection range of 20-mm grid was 3.1 cm in June and 2.36 cm in September, i.e., substantially smaller than that of the square mesh codend, suggesting a sharper selectivity performance of a grid (smaller SR/L_{50} ratio). The 15-mm sorting grid (BS15) showed poor selectivity for *M. merluccius* (L_{50} of 5.9 cm, SR of 3.5 cm).

Trachurus trachurus: The 36-mm square mesh codend showed a slightly higher L_{50} (14.0 cm) for horse mackerel than the 20-mm sorting grid (13.2 cm) (Table 3). The 15-mm grid had an L_{50} of 12.0 cm, which is exactly the current minimum landing size of this species. The selection range (SR) obtained with the 36-mm square mesh codend was substantially narrower than that obtained with the 20-mm sorting grid (Table 3).

TABLE 3. – Estimated selection parameters (L_{50} = mean selection length, SR = selection range) and their standard errors (SE) for most important species. The minimum landing size (MLS) for the species is shown for comparison with the L_{50} .

Sorting device	Month	MLS (cm)	L_{50} (cm)	(SE)	SR (cm)	(SE)	SR/L_{50}
<i>Merluccius merluccius</i> , European hake							
SM36	Jun	20	18.47	1.42	5.07	0.59	0.27
BS20	Jun		13.14	0.42	3.13	0.44	0.24
BS20	Sep		13.45	0.24	2.36	0.29	0.12
BS15	Jun		5.88	0.34	3.48	0.35	0.59
<i>Trachurus trachurus</i> , Atlantic horse mackerel							
SM36	Jun	12	14.03	0.87	2.48	0.74	0.18
BS20	Jun		13.22	0.36	4.55	0.50	0.34
BS20	Sep		13.13	0.74	3.33	0.70	0.25
BS15	Jun		12.05	0.25	4.24	0.23	0.35
<i>Trisopterus minutus capelanus</i> , Poor cod							
SM36	Jun	11	17.53	7.02	4.27	2.96	0.24
BS20	Jun		15.71	0.32	3.14	0.55	0.20
BS15	Jun		8.82	0.42	2.17	0.26	0.25
<i>Mullus barbatus</i> , Red mullet							
BS20	Sep	11	10.4	0.45	3.9	0.53	0.38
<i>Scomber scombrus</i> , Atlantic mackerel							
BS20	Jun	18	14.25	1.59	4.25	1.48	0.30
<i>Citharus linguatula</i> , Spotted flounder							
SM36	Jun	nr	9.27	1.17	3.08	2.65	0.33
BS20	Jun		10.62	0.24	6.08	0.54	0.57
BS20	Sep		8.97	0.7	3.80	0.74	0.42
BS15	Jun		9.82	0.3	3.06	0.33	0.31
Triglidae, Gurnards							
SM36	Jun	nr	12.63	1.08	2.31	0.49	0.18
BS20	Jun		9.76	0.18	4.12	0.05	0.42

nr MLS not regulated

Trisopterus minutus capelanus: For poor cod, the 36-mm square mesh codend and the 20-mm grid showed L_{50} values of 17.5 cm and 15.7 cm respectively (Table 3). These values are 5-7 cm above the current MLS of this species (11 cm); that is, fishermen would lose a greater part of the catch of this species. The 15-mm grid achieved an L_{50} of 8.8 cm. The estimated selection ranges of the 36-mm square mesh codend (4.3 cm) and the 20-mm sorting grid (3.14) are *relatively similar*, suggesting that for *T. minutus capelanus* the same selectivity performance (sharpens) can be achieved with both types of selection technique.

Mullus barbatus: The L_{50} (10.4 cm) for this species obtained with the 20-mm sorting grid was close to the MLS (11 cm) of this species (Table 3). No data were obtained with the square mesh codend because red mullet is a target species of demersal trawl fishery only in late summer and autumn.

Scomber scombrus: With the 20-mm grid, the L_{50} of 14.3 cm for *S. scombrus* was 4 cm below the

MLS (Table 3), suggesting that a substantially larger grid spacing would be needed to achieve adequate selectivity for this species.

Citharus linguatula and Triglidae: These are commercially exploited species but have no minimum landing size. The L_{50} of *C. linguatula* was 9.3 cm with the 36-mm square mesh codend. With both sorting grids the L_{50} was similar (9.8-10.6 cm; Table 3). The L_{50} of Triglidae were 9.8 and 12.6 cm with the 20-mm sorting grid and the 36-mm square mesh codend respectively. The square mesh codend showed a narrower selection range than the 20-mm grid (Table 3).

DISCUSSION

Iberian Mediterranean bottom trawl fisheries have shown an excessive increase in the fishing effort that has led to overexploitation of resources. The use of commercial small mesh size (40 mm knotted polyamide –PA–) codends has led the yield

per recruit to diminish with time as immature, first-age classes individuals are caught (Caddy, 1993). New sorting techniques other than diamond-shaped mesh codends, such as square mesh and sorting grids, are required to reduce catches of not-targeted fish, which can reach up to 34% of the total catch in weight in the Mediterranean (Sánchez *et al.*, 2004). Our trials show that the 36-mm square mesh codend and the 20-mm sorting grid are both useful in reducing the catch of undersized hake and horse mackerel in the NW Mediterranean multispecies trawl fishery (L_{50} close to the MLS). Our L_{50} estimated for hake with the 20-mm sorting grid (ca 13.3 cm) is close to that (14.2 cm) estimated earlier by Sardà *et al.* (2005) with a similar 20-mm grid. However, our estimates of selection range (3.1 and 2.4 cm) are substantially smaller than theirs (7.3 cm), suggesting that small changes in rigging of the grid may cause major changes in SR. Our selectivity parameters for hake with the 40-mm square mesh (L_{50} = 18.5 cm, SR = 5.1 cm) were higher than those reported in the Balearic Islands (L_{50} = 15.4 cm, SR = 4.5) (Guijarro and Massuti, 2006), probably due to the use in the islands of a thinner knotted PA netting operating in deepwater (>500 m) and at a lower speed (2.5 knots).

The 20-mm sorting grid also came out as an effective selection device for red mullet. However, in case of smaller commercial species such as poor cod, the 36-mm square mesh codend and the 20-mm sorting grid would release large quantities of individuals that are above the MLS. Fishermen for whom this species is a significant target species would experience marked catch losses. Therefore, these devices are probably not acceptable for the fishing industry. On the other hand, for Atlantic mackerel the 20-mm spacing in a grid appears to be too small, so a trawl equipped with such a grid would retain large quantities of undersized mackerel.

It is also likely that seasonal changes in species distribution and recruitment as well as the different ability of various species to escape the devices may greatly affect the selection. The experiments were performed in two seasons, because the area is characterised by a relatively high abundance of hake in June and red mullet in September. Other very abundant species in the fishery such as the spottail mantis shrimp (*Squilla mantis*), the blue leg swimming crab (*Liocarcinus depurator*), the common octopus (*Octopus vulgaris*), and the red bandfish (*Cepola macrophthalma*) are not selected by sorting grid and

square mesh, and they are not monitored because no MLSs are in force.

To optimise the overall selection performance in bottom-trawl fisheries in the Mediterranean, it may be necessary to use different selection techniques (e.g. mesh size/grid-spacing) for different seasons and for different fishing grounds. One solution will not work in all conditions.

This experiment highlights well the difficulty of improving size-selection in a multispecies fishery with a single selection technique. Clearly, the same mesh size or sorting grid spacing is not suitable for all species: it will be too large for some species and too small for others, and optimal selection could be achieved only for a few species. Requiring one mesh size (or grid spacing) to catch all these species all year round in various fishing grounds and fishing depths inevitably results in high discards and/or high catch-losses. Nevertheless, even if a precise optimum is not achieved for all species, a general increase in trawl selectivity in the Mediterranean Sea would increase the average age-at-capture for most commercial species, and would therefore improve the overall situation, increasing the long-term total yield from the fishery. It is noticeable that the use of squared mesh codends and sorting grids reduces discards and benefits the general community.

To attain marked improvements in this type of highly multispecies fishery, there should be a selectivity system in which the different type of species are first separated from each other, and then sorted by size (i.e. a multiple selection system). Effective improving of size-selection requires understanding season and depth variations of target and by-catch species, what makes difficult implementing a single mesh size or grid spacing in the Mediterranean demersal trawl fishery. Clearly, more focus should be given in the development of species selectivity to make the multispecies fishery in the Mediterranean sustainable.

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