

Assessment of the relative catch performance of hake, red mullet and striped red mullet in a modified trawl extension with T90 netting

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Summary: We studied the relative catch performance of a modified trawl fitted with an extension piece using a 90° turned mesh (T90) in comparison with a standard trawl net used in NW Mediterranean bottom trawl fisheries employing a diamond mesh net. The comparison was made by means of paired experimental hauls using the same fishing vessel with alternate deployments of the standard net (control) and the experimental net. We used the catch comparison approach for three target species of the fishery: European hake, red mullet and striped red mullet. Our results show that the experimental net significantly reduces the catches of small-size hake and red mullet (though there was no discernible difference for striped red mullet), reducing unwanted catches of regulated species under the Landings Obligation. The overall catch rates of hake, pooled over all sizes, also increased by an estimated 50%, while the catch rates of red mullet and striped red mullet were significantly lower. However, considering all commercial species, the experimental net produced losses of commercial catch and income estimated at 17% and 18%, respectively, which may pose a barrier to the adoption of this relatively simple, inexpensive solution.

Keywords: catch comparison; demersal trawl fisheries; T90 net; mesh size; Mediterranean Sea.

Comparación del rendimiento relativo de captura de merluza, salmonete de fango y salmonete de roca en un arte de arrastre modificado con una extensión con malla T90

Resumen: Estudiamos el rendimiento relativo de captura de un arte de arrastre con una pieza de extensión con malla girada 90° (T90) en comparación al arte de arrastre estándar usado en una pesquería del Mediterráneo noroccidental que usa extensión de malla romboidal. La comparación se llevó a cabo mediante lances experimentales pareados usando el mismo barco de pesca con lances alternos de la red estándar (control) y la red experimental. Esta comparación de captura se hizo para 3 especies objetivo de la pesca, la merluza, el salmonete de fango y el salmonete de roca. Los resultados muestran que la red experimental redujo de manera significativa las capturas de individuos pequeños de merluza y salmonete de fango (pero no se detectó efecto significativo en el salmonete de roca), contribuyendo a reducir las capturas no deseadas de especies reguladas por la Obligación de Desembarco. Las tasas de captura de merluza, promediadas para todas las tallas, aumentaron en un 50%, mientras que las tasas de captura de los dos salmonetes fueron significativamente inferiores. La red experimental produjo pérdidas adicionales de captura comercial e ingresos, que se estiman en 17 y 18%, respectivamente, lo que puede significar una barrera para la adopción de esta solución sencilla y barata.

Palabras clave: comparación de capturas; pesquerías de arrastre; red T90; tamaño de malla; mar Mediterráneo.

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INTRODUCTION

The EU discards ban embedded in Art. 15 of EC 1380/2013 EC 2013, or the Landing Obligation, is aimed at reducing discards in EU fisheries and

working towards more selective fishing by incentivizing fishers to apply appropriate technical solutions, among other changes in fishing practices. The policy objective behind the Landing Obligation is the perception that fisheries discards are a structural deficiency

of European fisheries (EC 2012) and that resources that can be used productively in the maritime economy are wasted. The discards ban aims at rationalizing the fishing process by means of more selective gears and sustainable practices (Gullestad et al. 2015). In Mediterranean fisheries, the quantity of discards is perceived to be high, but with important variation across fleet segments or fishing gear (Uhlmann et al. 2014). Bottom trawl fisheries are among the fisheries with the highest amount of discards, both total and of regulated species. For example, Tsagarakis et al. (2014) estimate discard rates of 20% to 65% of the total catch in Spanish Mediterranean bottom-trawl fisheries, while discards of undersize individuals of regulated species such as *Trachurus* spp. or Sparidae vary from 18% to 77% of the catch of each species (Bellido et al. 2017). However, the quantity of discards is generally known with low precision due to the high variability in the quantity of discards, even within a single fishery, because of the varied reasons for discarding (Martinet et al. 2007, Uhlmann et al. 2014).

The Landing Obligation entered into force progressively, with the discards ban in small pelagics fisheries effective as of 1 January 2015 and its application to all regulated marine species by 1 January 2019. In western Mediterranean bottom trawl fisheries, the discards ban for species that define the fisheries, the European hake *Merluccius merluccius* and the red mullet *Mullus barbatus*, entered into force on 1 January 2017. With the current legal bottom-trawl mesh sizes of 40 mm (square mesh) or 50 mm (diamond mesh), it is not possible to avoid catching unwanted individuals of these species, and particularly so for *M. merluccius*, which has an estimated mean retention length of 10 to 16 cm TL in these meshes, compared with a minimum conservation reference size (MCRS) of 20 cm (Bahamon et al. 2006, Guijarro and Massutí 2006, Sala and Luchetti 2011).

Investigating the effect of simple modifications to the current bottom trawl is interesting because these modifications may work towards reducing unwanted bycatch without undue changes to the fishing practices of fishers or expensive modifications. It is important to note that the Landing Obligation may result in additional sorting and handling costs estimated at 0.50 €/kg or higher (Sartor et al. 2016), hence the importance of devising inexpensive solutions that mitigate the effects of the Landing Obligation without imposing excessive costs.

The objective of this work is to investigate the relative catch performance of a simple modification to the extension piece of a bottom trawl with regard to the two species that characterize the fishery, the European hake *Merluccius merluccius* and the red mullet *Mullus barbatus*, with additional data on the striped red mullet *M. surmuletus*, which is also caught in this fishery. Our research focused on the substitution of a standard diamond-mesh extension piece of 53 mm, as used in NW Mediterranean bottom trawls, with a similar piece with netting turned 90° (T90). This modification is based on the improved selection properties that this netting has shown when used in codends in Northern European fisheries (Madsen et al. 2012, Wienbeck et

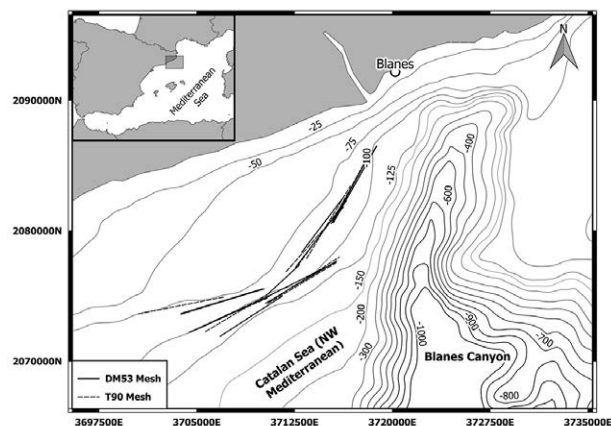


Fig. 1. – Study area.

al. 2011), due to increased resistance of the T90 netting to close under pressure compared with the traditional orientation.

MATERIALS AND METHODS

Data

The study area comprises two commercial fishing grounds of the continental shelf of NE Spain (Fig. 1). The shallower fishing ground, “Les Quaranta”, covers 21 km² on sand and gravel bottoms of 60-90 m depth. The deeper fishing ground, “Els Capets”, covers 24 km² on muddy-sand bottoms between 90 and 120 m depth. Both fishing grounds are routinely operated by the local trawl fleet of the port of Blanes, practising a mixed bottom trawl fishery targeting *Merluccius merluccius*, *Mullus* spp. and various cephalopods and finfish.

The sampling design consisted of paired hauls using a single local commercial fishing vessel of 15 m LOA and 261 kW, alternating the standard extension piece used in the area with the experimental T90 extension piece over consecutive days over the same geographical coordinates (Fig. 1). The experiment was carried out during daytime in 2016 on 10-11 August, 26-27 September and 13-14 December, with a total of 24 fishing operations corresponding to 12 pairs. Four to five one-hour hauls were performed daily at a towing speed of 2.7-2.9 knots. The specifications of the fishing gear are shown in Table 1.

The control net, referred to hereafter as DM53, was fitted with a codend of 40-mm square-mesh knotting (45°) and a 53-mm diamond-mesh knotting (0°) exten-

Table 1. – Nominal sizes of the standard (DM53) and the experimental net (T90).

Codend/extension parameters	DM53	T90
Nominal mesh size, codend (mm)	40	40
Nominal mesh size, extension (mm)	53	50
Netting material	PE	PE
N° meshes around codend circum.	130	130
N° meshes codend length	55	55
codend length (m)	1.40	1.42
N° meshes extension circum.	206	140
N° mesh extension length	81	100
Longitudinal extension length (m)	5.15	4.36

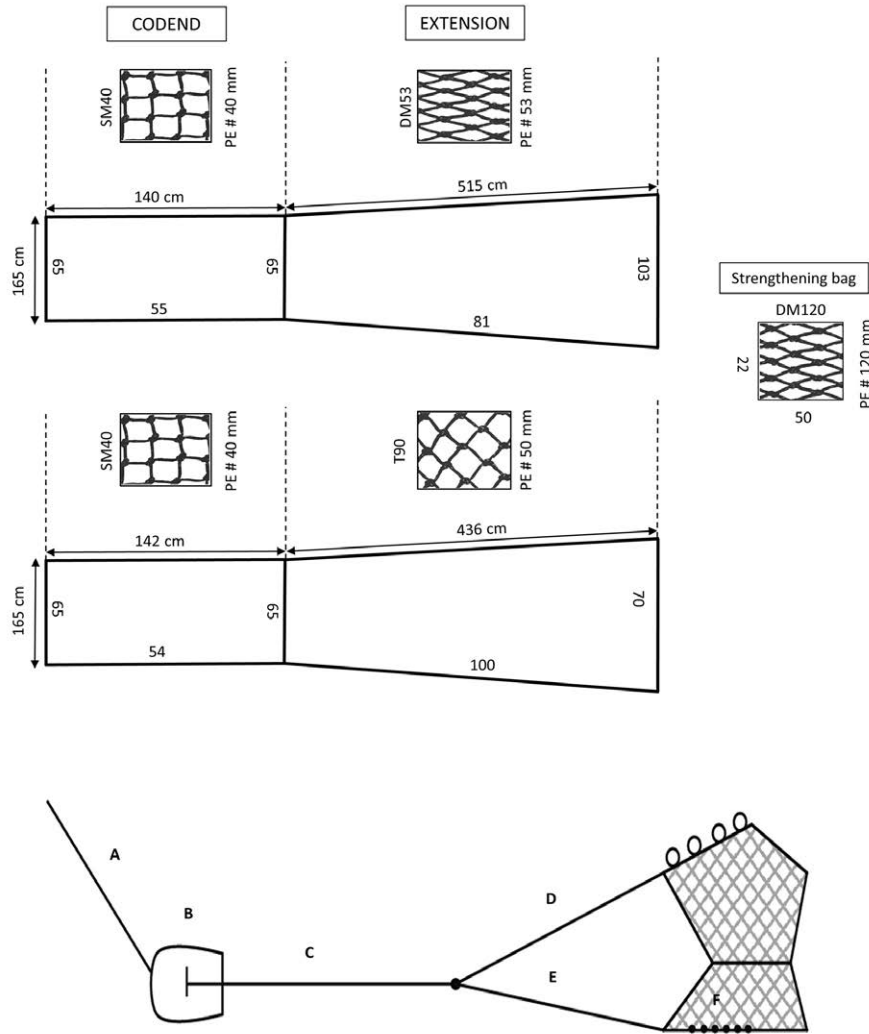


Fig. 2. – Characteristics of the trawl with details of the control and experimental aft parts of the net. In the lower panel: A, wire Ø16 mm, 265-330 m; B, trawl door (1250×770 mm), –110 kg; D, combinations rope Ø 22 mm, 220 m; E, wire Ø14 mm, 23 m; F, chain, 3 m.

sion piece (Fig. 2), following the standard trawl used in the area, which complies with the local fisheries regulation (EC 1967/2006: EC 2006). In the experimental net, the netting in the extension piece was replaced with a 50-mm diamond mesh mounted in T90 orientation (T90, Hansen 2004).

After hauling in the catch, the target species *M. merluccius* and *Mullus* spp. were sorted, weighed and sized (cm TL) individually, while the rest of the commercial catch was identified to species level and weighed. No subsampling of the catch was necessary given the number of specimens caught.

Statistical analysis

Catch comparison analysis

The experimental setup lacked a small mesh cover or other similar device to quantify the number of individuals passing through the extension piece, precluding the computation of absolute selectivity. For this reason, we chose the catch comparison method for the analysis of the experimental results. For each target species,

we compared the catch efficiency of the standard trawl (control; 1) with that of the experimental trawl (2), based on the catch comparison method (Holst and Revill 2009) used in Krag et al. (2014) and Sistiaga et al. (2015), for example. This method estimates the average, relative change in length-dependent catch efficiency. For our set of 12 comparisons, the experimental average catch comparison rate (CC_l) is given by the following expression:

$$CC_l = \frac{\sum_{i=1}^{12} n2_{li}}{\sum_{i=1}^{12} n1_{li} + \sum_{i=1}^{12} n2_{li}} \tag{1}$$

where $n1_{li}$ and $n2_{li}$ are the number of fish measured in each length class l in the control and experimental trawls, respectively (Sistiaga et al. 2015). The experimental CC_l can be modelled by the following functional form (Krag et al. 2014):

$$CC(l, \mathbf{v}) = \frac{e^{f(l, q_0 \dots q_k)}}{1 + e^{f(l, q_0 \dots q_k)}} \tag{2}$$

where f is a polynomial of order k with coefficients q_0 to q_k so $\mathbf{v}=(q_0, \dots, q_k)$. Equation (2) gives the probabil-

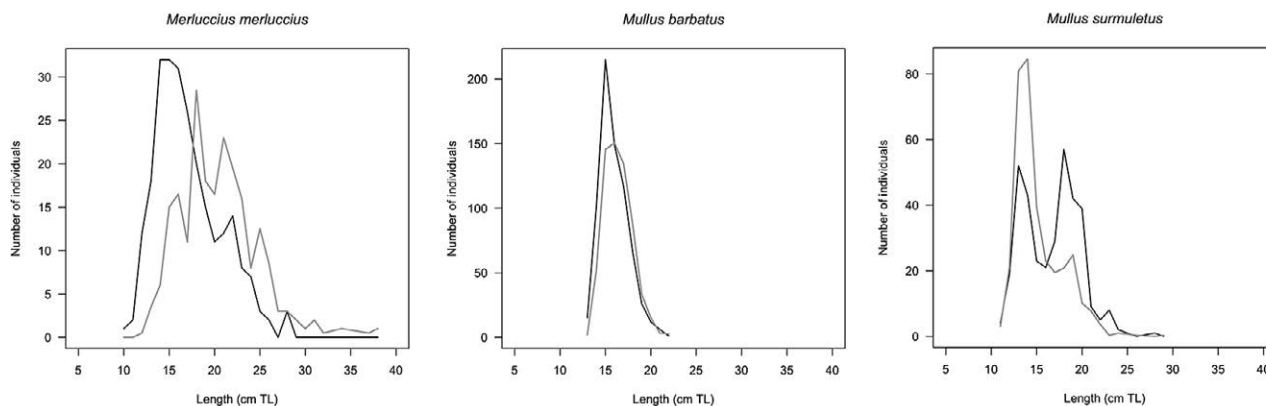


Fig. 3. – Length frequencies of the target species. Black line, standard configuration with a 53-mm diamond mesh; grey line, experimental trawl fitted with 50-mm T90 mesh extension.

ity of catching a fish of length l with trawl 2 provided it was captured by any of the two trawls. A value of $CC(l, \nu)=0.5$ implies that the likelihood of capturing a fish of size l is the same for the two trawls (i.e. both trawls would have the same catch efficiency). The values of the polynomial coefficients in ν are estimated by minimizing the log-likelihood:

$$LL = - \sum_l (n1_l \cdot \log(1 - CC(l, \nu)) + n2_l \cdot \log(1 - CC(l, \nu))) \quad (3)$$

where $n1_l$ and $n2_l$ are the numbers of fish of length l summed over hauls.

Following Krag et al. (2014), we tested all possible polynomials up to the fourth degree, i.e. 2^5 combinations of parameters q_0, q_1, q_2, q_3, q_4 . Selection of the best model among the 32 candidate models was based on choosing the model with the lowest Akaike information criterion (Akaike 1974). We used the double bootstrap approach with 10000 repetitions to estimate the 95% confidence limits (Efron 1982) of the polynomial coefficients and the $CC(l, \nu)$ curve for length classes with 10 individuals or more (10 to 38 cm TL for hake, 13 to 22 cm TL for red mullet, and 11 to 29 cm for the striped red mullet). The double bootstrap method accounts for between-haul variation and within-haul uncertainty on the size structures, and was applied by resampling (with replacement) among the 12 haul pairs and resampling (with replacement) among the length frequencies.

A significant difference in catch efficiency between the two trawls was determined when the 95% confidence interval did not overlap the baseline of no difference in catch performance, $CC(l, \nu)=0.5$.

Catch ratio analysis

Additionally, the ratio between the catch efficiency of the control and test trawl nets for a given length, l , was computed with the following expression for the experimental data:

$$CR_l = \frac{\sum_{i=1}^{12} n2_{l_i}}{\sum_{i=1}^{12} n1_{l_i}} \quad (4)$$

with the following functional form, based on Equations (1) and (4):

$$CR(l, \nu) = \frac{CC(l, \nu)}{1 - CC(l, \nu)} \quad (5)$$

If the catch efficiency were the same in both trawls, the catch ratio would be equal to 1. Estimation of mean $CR(l, \nu)$ and its confidence intervals for each length class was embedded in the double bootstrap analysis explained above.

The catch comparison and catch ratio models were fitted with the help of library *lme4* of the computing package for R (version 3.3.2), using an ad hoc script. The size frequencies of the standard and the experimental net were compared statistically by means of a Kolmogorov-Smirnov test (command *ks.test* of R version 3.3.2).

RESULTS

The size frequency distributions of the three species under study are reported in Figure 3. The size frequency of hake (Fig. 3, left) was shifted to the right in the experimental trawl, with a modal length of capture around 18 cm TL, while the mode in the control trawl was 15 cm. In the case of red mullet (Fig. 3, center) the size frequency observed lies in a narrow range of 13 to 22 cm (10 size classes), with a single peak at 15 cm for the control trawl and a mode around 16 cm for the experimental trawl. The striped red mullet (Fig. 3, right) showed a bimodal size frequency for the control trawl, with peaks at 13 and 18 cm, while the experimental trawl produced a larger quantity of individuals in the first mode (13-14 cm) and a barely noticeable second mode.

A Kolmogorov-Smirnov test of difference between the size frequencies of the standard and the experimental net showed no significant differences (hake, $D=0.231, p=0.493$; red mullet, $D=0.203, p=0.995$; striped red mullet, $D=0.176, p=0.954$).

The length-dependent catch comparison analysis for the three species produced the models whose parameters are given in Table 2 and plotted in Figure 4 (left panels). In the case of hake and red mullet, the best models selected included polynomial terms of degrees 0, 1, 2, while in the case of the striped red mullet a constant intercept polynomial produced the best results

Table 2. – Parameter estimates of the selected models (coefficients of the polynomial models in Eq. 2), with 95% confidence intervals.

Species	Model	Parameter	Estimate	95% CI
Hake (<i>Merluccius merluccius</i>)	Quadratic	q_0	-3.031	-7.125 - 1.064
		q_1	0.194	-0.203 - 0.591
		q_2	-0.0018	-0.0114 - 0.0078
Red mullet (<i>Mullus barbatus</i>)	Quadratic	q_0	-17.672	-8.082 - -27.26
		q_1	1.941	0.788 - 3.095
		q_2	-0.053	-0.086 - -0.0181
Striped red mullet (<i>Mullus surmuletus</i>)	Linear	q_0	-0.457	-1.032 - 0.117

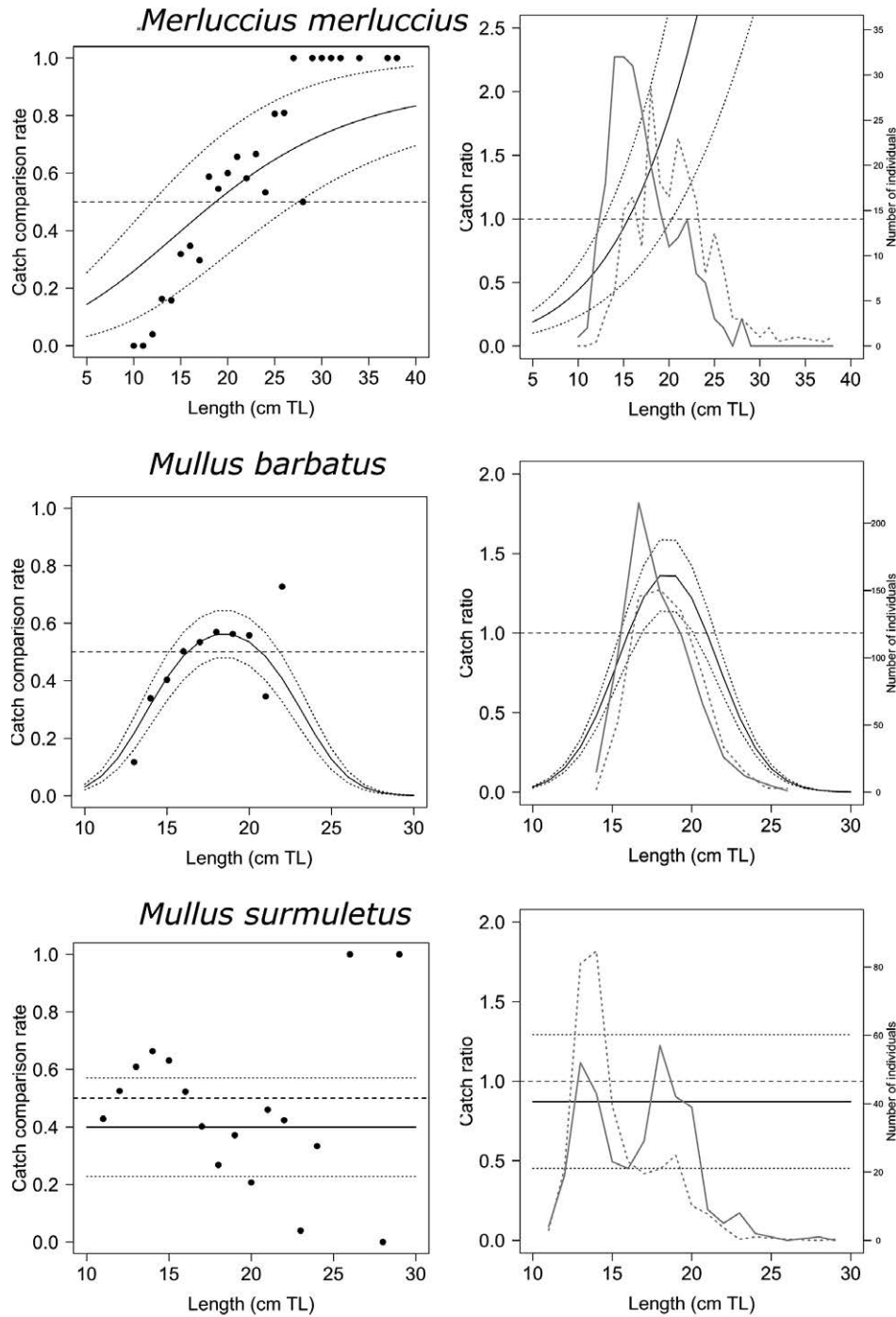


Fig. 4. – (left) Catch comparison curves for the models selected: filled circles are observed proportions, pooling all trawl hauls. Solid lines represent the mean, dotted lines 95% confidence intervals. The level of no effect ($CC(l, \nu)=0.5$) is shown by the horizontal dotted line. (right) Catch ratio curves (solid black lines, mean; dotted black lines, 95% confidence intervals) and observed catch frequency (grey lines, continuous control trawl; dotted lines, experimental trawl). The level of no effect ($CR(l, \nu)=1.0$) is shown by the horizontal dotted line. Model parameters are shown in Table 2.

Table 3. – Fit statistics for the catch comparison curves; df, degrees of freedom; AIC, Akaike information criterion.

Species	AIC	deviance	df	p-value
Hake	286.66	278.7	130	0.98
Red mullet	341.06	333.0	93	0.99
Striped red mullet	256.1	248.1	87	0.97

(Table 2). The fit statistics of the models are given in Table 3. The p-values obtained were above 0.05 for all three species, suggesting that the data are well described by the models.

Figure 4 (top, left) shows that the experimental trawl has higher catches of hake larger than 16 cm (approximately) than the standard trawl, with a strong reduction in catches of individuals in the smaller size classes. In the case of red mullet (Fig. 4, middle, left), a slightly higher, but not statistically significant, rate of catches was detected for individuals in the range 16–20 cm, with significantly reduced catches below 15 cm in the experimental trawl (confidence intervals below the baseline of 0.5). For striped red mullet (Fig.

4, bottom, left) the relative catches of 13 to 15 cm fish were higher in the experimental net, but while the experimental net had lower catch rates for lengths greater than 15 cm, the difference was not statistically significant from the standard trawl (confidence intervals within the baseline of 0.5).

The quantitative differences in the catch efficiencies are shown in the catch ratio curves (Fig. 4, right panel). In the case of hake (Fig. 4, top, right) the experimental net caught fewer individuals smaller than 12 cm and more individuals larger than 20 cm. In the case of red mullet, the catch ratio of the experimental trawl was significantly lower than the standard for sizes below 15 cm and higher than 23, with significantly higher catch rates between 17 and 20 cm. The experimental trawl did not produce significant differences in catch efficiency for striped red mullet. Table 4 shows the catch ratios, in percentage, between the two fishing gears (baseline of no effect=100%) for the typical fish sizes collected in the experiments (10 to 25 cm TL). Although the confidence intervals are wide, the experimental net had

Table 4. – Estimated catch ratios for different length classes (the majority of individuals of the three species are in the range 10 to 25 cm), using the standard trawl as baseline, for the models in Table 2 (see also Fig. 4, right). Values in parentheses are the 95% CI.

Catch ratio (%)	hake	red mullet	striped red mullet
CR(10, v)	43.83 (23.35-64.31)	3.15 (2.63-3.67)	
CR(11, v)	51.30 (27.33-75.26)	7.29 (6.09-8.49)	
CR(12, v)	59.82 (31.88-87.77)	15.18 (12.68-17.68)	
CR(13, v)	69.52 (37.04-102.00)	28.45 (23.76-33.15)	
CR(14, v)	80.50 (42.89-118.12)	48.01 (40.09-55.93)	
CR(15, v)	92.89 (49.50-136.29)	72.94 (60.91-84.97)	
CR(16, v)	106.81 (56.91-156.71)	99.75 (83.30-116.20)	
CR(17, v)	122.38 (65.21-179.56)	122.82 (102.56-143.07)	
CR(18, v)	139.73 (74.45-205.01)	136.14 (113.68-158.59)	
CR(19, v)	158.97 (84.70-233.24)	135.85 (113.44-158.26)	
CR(20, v)	180.22 (96.02-264.42)	122.05 (101.92-142.18)	
CR(21, v)	203.59 (108.48-298.71)	98.71 (82.43-114.99)	
CR(22, v)	229.19 (122.11-336.26)	71.87 (60.02-83.73)	
CR(23, v)	257.09 (136.98-377.19)	47.12 (39.34-54.89)	
CR(24, v)	287.36 (153.11-421.61)	27.80 (23.22-32.39)	
CR(25, v)	320.07 (170.54-469.61)	14.77 (12.34-17.21)	
CR(average, v)	150.21 (80.03-220.38)	65.74 (54.90-76.59)	87.22 (45.17-129.27)
Δ CR(average, v)	50.21 (-19.97-219.38)	-34.26 (-45.10-75.59)	-12.78 (-54.83-128.27)

Table 5. – Mean catch composition (weight and value) of 12 hauls with the standard net (DM53) and with the experimental net (T90). Income shown is the ex-vessel value.

		DM53		T90	
		Catch (kg)	Income (€)	Catch (kg)	Income (€)
Commercial species	Fishes (total)	151.8	1048.27	128.9	817.90
	<i>Lophius</i> sp.	24.9	225.10	17.9	161.82
	<i>M. barbatus</i>	37.8	205.63	35.0	190.40
	<i>M. surmuletus</i>	23.9	231.35	16.2	156.82
	<i>Merluccius merluccius</i>	11.7	109.63	14.5	135.87
	Other taxa	29.9	197.34	16.7	110.22
	<i>Pagellus erythrinus</i>	1.9	6.27	6.5	21.45
	<i>Trisopterus minutus</i>	21.8	70.85	12.2	39.65
	<i>Raja</i> sp.	1.0	2.10	0.8	1.68
	Cephalopods (total)	61.9	382.67	57.8	374.60
	<i>Alloteuthis media</i>	1.7	47.11	2.0	55.42
	<i>Eledone cirrhosa</i>	16.1	79.53	15.4	76.08
	<i>Illex coindetii</i>	23.3	107.88	18.8	87.04
	<i>Octopus vulgaris</i>	4.9	20.78	6.9	29.26
	<i>Sepia officinalis</i>	2.0	28.68	3.0	43.02
	<i>Sepia orbignyana</i>	13.9	98.69	11.8	83.78
	<i>Stichopus regalis</i>	4.8	385.92	3.6	289.44
Total landings		219.5	1816.86	181.1	1481.93
Total catches (kg)		419.20		354.00	
Discards (kg)		199.7		172.9	
Discards ratio (%)		47.6		48.8	

a lower catch efficiency of individuals of 15 cm TL and below for both hake and red mullet. On the other hand, the average catch efficiency of the experimental net for hake was 150%, i.e. overall it caught 50% more quantity of hake regardless of size. In the case of red mullet, a loss of 34% could be expected, and for striped red mullet a loss of 13% (Table 4).

Computing the empirical catch ratio (Eq. 4) for sizes below an MCRS of 20 cm TL for hake and 11 cm TL for both red mullets resulted in a value of 52% for hake, i.e. the experimental trawl caught about half the quantity of undersize hake that the standard trawl caught. In the case of red mullets, no undersize specimens were caught by the standard or the experimental trawl.

In addition to the study target species, the catches of accompanying species of commercial interest was also modified in the experimental trawl, as shown in Table 5. In general, both catches and total discards were lower in the modified net, although the proportion of total discards was similar: 47.6% and 48.8% respectively. All fish species except *M. merluccius* and *Pagellus erythrinus* showed lower catch rates with the modified net. The overall catch of invertebrates (commercial cephalopods and the echinoderm *Stichopus regalis*) were lower in the modified net, although some species of cephalopods (*Alloteuthis media*, *Octopus vulgaris* and *Sepia officinalis*) showed higher catches. In economic terms, the modified net produced a 17% decrease in the marketed catch and an 18% decrease in the commercial value.

DISCUSSION

Our results show that introducing the T90 mesh in the trawl extension piece reduces the likelihood of capturing small individuals for two important commercial species of Mediterranean fisheries, the European hake (*Merluccius merluccius*) and the red mullet *Mullus barbatus*. This result is relevant in terms of fisheries management because these species fall under the Landing Obligation in the transition period 2017-2019. In the case of *M. merluccius*, the adoption of this modification to the trawl extension helps bring L50 well below the MCRS with current trawl regulatory mesh size, more in line with the 20 cm legal size, while at the same time increasing catch rates. For the two red mullet species *Mullus* spp., regulatory mesh size already catches individuals larger than the MCRS of 11 and the modification would result in a non-negligible catch reduction.

The introduction of modifications to fishing gear that improve fisheries selectivity will be successful only if these modifications are practical (easy to use and inexpensive), can be acceptable to industry and managers, have low environmental impact and are easily enforceable (Catchpole et al. 2008). Simple modifications to the trawl net such as the one proposed here meet these requirements and are particularly interesting for hake, whose exploitation is excessive and relies to a large extent on undersize individuals. Other authors have shown the selective properties of T90 net-

ting either in the codend or the trawl body. T90 netting has interesting properties regarding species and size selection when used in codends. For instance, Deval et al. (2016) tested codends with T90 meshes in four commercial shrimps of eastern Mediterranean trawl fisheries and showed that the percentage of escapes for all four species increases, as well as obtaining an increase in the L50. In Northern European fisheries, T90 codends have been subject to comprehensive studies that show a clear improvement in selectivity (Moderhak et al. 1999) and in the quality of the fish marketed (Hansen 2004). Despite the number of studies carried out with T90 codends, we are not aware of any other studies testing selection at the level of trawl extension.

The proposed modification does, however, significantly reduce the total commercial catch of the vessel, by 17% in volume and 18% in value. Most of the species affected by this reduction are bony fishes, in particular small anglerfish (*Lophius* sp.) and poor cod (*Trisopterus minutus*). It is expected that the economic loss can be partially offset by decreased sorting time and costs and decreased costs related to compliance with the Landings Obligation, but certainly short-term losses of income are a barrier to the adoption of more selective technologies. Nevertheless, this short-term reduction of commercial catch can be justified by the need to reduce fishing mortality in the Mediterranean demersal fisheries for overexploited target stocks. It should lead to a recovery of stocks and provide higher yields in the medium to long term Merino et al. (2015).

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