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An overview of bottom trawl selectivity in the Mediterranean Sea

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Abstract

In the Mediterranean Sea, where bottom trawling for demersal species is the most important fishery in terms of landings, around 75% of the assessed fish stocks are overfished. Its status as one of the world's most heavily exploited seas and the one subject to the highest trawling pressure has become a global concern. An extensive overview of bottom trawl selectivity studies was performed to assess the sustainability of this fishery in the Mediterranean. The selectivity parameters were collected from 93 peer-reviewed publications from 10 countries, totalling 742 records and 65 species. Our review highlighted that *i*) the catch of the bottom trawls commonly employed in the Mediterranean, although they comply with current codend mesh regulations, still includes immature individuals of 64-68% of the species investigated, and individuals under the minimum conservation reference size (*MCRS*) of 78% of the species investigated, and that *ii*) the *MCRS* set for 59% of the species analysed is well below their length at first maturity and is therefore ecologically inadequate. Although square-mesh codends are slightly more selective, the models developed herein demonstrate that improving size and species selectivity would require considerably larger meshes, which may significantly reduce profitability. The urgent need to mitigate the biological impacts of bottom trawling in the Mediterranean should be addressed by promoting the adoption of more ecologically sustainable fishing gears through the introduction of more selective meshes or of gear modifications.

Keywords: Selectivity; Bottom trawl; Sustainable fishery; Demersal fish; Mediterranean Sea.

Glossary

BRD: Bycatch Reduction Device, DM: Diamond Mesh, GSA(s): Geographical Sub-Area(s) of the Mediterranean FAO-GFCM subdivision, JTED: Juveniles and Trash Excluder Device, LFM: Length at First Maturity, L50: 50% length retention probability, MCRS: Minimum Conservation Reference Size, MS: Mesh Size, MMS: Minimum Mesh Size, MeasMS: Measured Mesh Size, NMS: Nominal Mesh Size, SF: Selection Factor, SM: Square Mesh, SR: Selection Range, TD: Twine Diameter, TED: Turtle Excluder Device, T90: Turned 90° (mesh).

Introduction

In the past thirty years, the growing understanding of species habits and behaviours has made harvesting of marine stocks increasingly efficient (Whitmarsh, 1990; Pikitch *et al.,* 2004; Squires & Vestergaard, 2013). Technological and technical advances have improved fishing gears and enhanced fishing operations and the access to resources. The general awareness of the environmental problems induced by such heavy exploitation has also been increasing (Berkes *et al.,* 2006; Maynou *et al.,* 2011; Iversen, 2012). Notably, bycatch (Lewison *et al.,* 2004b,a; Eayrs, 2007; Davies *et al.,* 2009), discards (Kelleher, 2005; Feekings *et al.,* 2012) and the physical impact of towed gears (Lucchetti & Sala, 2012; Eigaard *et al.,* 2016; Gascuel *et al.,* 2016) have come to be recognized as the main problems undermining the sustainability of this fishery.

In the Mediterranean Sea, the strong demand for and high commercial value of small fish, crustaceans and molluscs, which are used in typical dishes and in fish fries, has long been met using gears with small mesh sizes (*MS*s), which however involve significant bycatch, hence discarding. Among other organisms, bycatch includes undersized fish and low-value species that may be targeted by other fisheries as well as individuals of endangered or protected species caught unintentionally (Crowder & Murawski, 1998; Zhou, 2008; Petter Johnsen & Eliasen, 2011). The main problem with the bycatch of bottom trawls is that most individuals may not survive, because they are damaged in the net, they are hauled up from the bottom too quickly, or are returned to the sea too late. Since these fish and shellfish species are part of a population and ecosystem, their removal affects the food chain, and ultimately the economic and social aspects of the fishery, in several ways (Pascoe, 1997; Innes & Pascoe, 2010).

In the Mediterranean, discarding and bycatch are due to the facts that most fishing gears and practices are insufficiently species- and size-selective (Tsagarakis *et al.,* 2014, 2017) and that they target species that often inhabit areas occupied by a wide range of other species (multi-species fishery). Managing a multi-species fishery is fraught with difficulties, because the different shapes, behaviours, adult sizes and minimum conservation reference sizes (*MCRS*s) of most fish and invertebrates prevent targeting a single species in shared habitats. As a result, fish stock management in the Mediterranean is mainly based on input restrictions, i.e. closed areas and seasons, limitations of the fishing effort and minimum *MS* (*MMS*).

In bottom trawl fisheries, the minimum size of the organisms that can legally be caught or landed (*MCRS*) can be considered as the only output restriction (Lleonart & Maynou, 2003; Lucchetti *et al.,* 2014; Nolde Nielsen *et al.,* 2015). However, since the *MCRS* strongly depends on the *MMS*, the two measures should always be addressed together (Valdemarsen & Suuronen, 2003). In Mediterranean bottom trawling, most restrictions concern mesh geometry and size. In this regard, the Resolution of the General Fisheries Commission for the Mediterranean GFCM31/2007/3 (GFCM, 2007) encourages Mediterranean Member States to replace the diamond mesh (*DM*) in the codend with the 40 mm square mesh (*SM*). However, since in most Mediterranean countries small and undersized specimens are in strong demand, the mesh change can severely affect fishery profitability (Kelleher, 2005). Clearly, it is difficult to define an *MMS* for towed nets in a multi-species fishery, because a size that is appropriate for one species will be unsuitable for several others (Stewart, 2001). The objective for such fisheries is therefore to find an *MMS* that minimizes the retention of undersized fish and does not penalize revenues.

In recent years, numerous attempts, made to increase net selectivity and to reduce the capture and discard of non-target fish, have demonstrated that effective selection is greatly hampered by fish behaviour patterns. For a trawl gear to be truly selective, the fish entering the net should be filtered to ensure that those that are small enough to pass through the meshes can escape, whereas those above the *MCRS* are retained (Glass & Wardle, 1995; Glass *et al.,* 1995). Since the demonstration that most organisms escape from the trawl through the codend meshes (Beverton, 1963), most selectivity studies in the Mediterranean have investigated increases in codend *MS* to enhance selectivity (Stewart, 2001).

In the past 20 years, several studies have documented that technical changes to traditional gears, their design and/or their operation and the adoption of alternative fishing gears may improve the release of undersized fish as well as bycatch species (Kennelly, 1995; Wileman *et al.,* 1996; Broadhurst, 2000; Valdemarsen & Suuronen, 2003; Petetta *et al.,* 2020b). The changes usually involve the size, shape and twine diameter of the codend meshes.

The main objective of this study is to describe the state of the art of bottom trawl selectivity in the Mediterranean through a review of past and recent papers and of the grey literature, to assess whether the current regulatory framework is sustainable.

Materials and Methods

Trawl selectivity

The selectivity of a fishing gear is a measure of the selection process, describing the relative likelihood that fish of different sizes and species will be caught by the gear if there are equal numbers of each in the population (Wileman *et al.,* 1996). However, it is well established that no gear is endowed with 100% catch likelihood for a given species or a specific size range (i.e. above the *MCRS*), because some fish can avoid the trawl mouth, escape under the ground rope or swim through the meshes of the trawl body or of the codend.

In trawl selectivity studies, comparison of the size frequency distribution of the specimens caught in the codend and of those living in the area being investigated (when using the covered codend technique, these are the specimens found respectively in the codend and the cover) allows estimating selectivity curves. The simplest mathematical model that can be applied to estimate them is the “logistic curve” (Pope, 1975):

$$S_L = \frac{1}{1 + \exp\left(S_1 + S_2 \cdot L\right)} \qquad (1)$$

where

$$S_L = \frac{Number\ of\ fish\ having\ length\ L\ in\ the\ codend}{Number\ of\ fish\ having\ length\ L\ in\ the\ codend\ and\ in\ the\ cov} \quad (2)$$

L is the mean length interval point and S_1 and S_2 are constants.

The 50% retention length (*L50*) is the fish length at which 50% of the fish are likely to be retained in the codend, whereas *L25* and *L75* are the lengths at which respectively 25% and 75% of the fish are likely to be retained. The length range between *L25* and *L75* is the selection range (*SR*), which is symmetrical around *L50* and determines the slope and shape of the curve, expressing the efficiency of the selection (the smaller the *SR* the more efficient the selection process, since it approaches the “knife edge process”).

L50 can also be used to calculate the selection factor (*SF*), as follows:

$SF = L50/MS$ (Pope, 1975).

SF is a dimensionless value that allows comparing the selectivity results obtained in different studies for a certain species. In theory, using the same codend characteristics (*MS*, codend circumference, netting twine) should result almost in the same *SF*. Thus, *SF* can be considered as a species-specific parameter, because the *L50* for a certain species will increase with increasing *MS*. This factor should carefully be taken into account when discussing management measures.

Data collection

The references collected and analysed for this study were obtained from the grey literature (national reports, conference proceedings, etc.) and from peer-reviewed scientific journals. We adopted a stepwise search, as in previous studies (Hamilton & Baker, 2019). First of all, we searched the published literature using *Science Direct* and *Springer link* by employing predefined keywords (and their variants), which included a consolidated combination ("AND") of: "trawl", "selectivity" and "Mediterranean", with (1) mesh size; (2) codend; (3) other parameters (circumference, twine diameter etc.). The search was also conducted with keywords in Italian, French and Spanish to find works written in other languages (e.g. national reports).

All papers were first filtered, and only papers describing *MS*, *L50* and *SR* were included. When *SF* was not explicitly reported, we calculated it from the *L50* and *MS*. The effect of *MS* and mesh geometry, *TD* and codend circumference was also considered. However, the technical data on twine and codend circumference are rarely mentioned in papers and reports, mainly because *MS* and mesh geometry are the main drivers of selectivity. Therefore, in this study the effect of twine diameter (*TD)* and codend circumference on codend selectivity was assessed only for *DM* codends, for which a sufficient dataset was collected. Since some papers were published several years after the relevant selectivity experiments, we reported the year when the experiments had been conducted; if this information was not available, we reported the year of publication; if the experiment was conducted over two or more years, we reported the year when the experiment was completed.

To provide a graphic representation of the ratio of *L50* to length at first maturity (*LFM*), the *LFM* data of the main species were reviewed. When more than one source was found for a given species, the average *LFM* (defined here as the length at which 50% of a population becomes sexually mature for the first time) was calculated. If *LFM* data were available for both genders, we used the more conservative average value. Only data for the Mediterranean Sea were considered (Supplementary Table S1).

Finally the *MCRS*, i.e. the minimum legal size under which fish should not be caught, stored, landed or sold, set by European Regulation1967/2006 (EC, 2006), was included in the analysis to demonstrate the consequences of trawl selectivity (a similar approach can be adopted for the *MCRS* set in other non-EU Mediterranean countries).

The *LFM* is an important parameter in fisheries management and is the basis for setting the *MCRS* of target species. It is universally accepted that the most practical approach to preserve individuals under the *MCRS* is to set an appropriate *MMS*.

The results of this study focus on the selectivity of codends with *DMs* and *SMs*, according to Resolution GFCM/31/2007/3 (GFCM, 2007).

Data analysis

The selectivity data obtained from the literature review were used to model the relationship between *L50* and *SR* with *MS* and mesh geometry. From the operational viewpoint, a simple linear regression model offers several advantages such as robustness, transparency in calculations and standards and widely used statistical diagnostics. The model can be immediately recognized as:

$$y = b \cdot x + \varepsilon \quad (4)$$

where:
y denotes the response variables (*L50* or *SR*); x denotes the predictor variables (*MS*, *TD* or the codend rigging ratio, i.e. codend circumference/extension circumference; Sala & Lucchetti, 2010); b is the regression coefficient; and ε represents measurement error as well as any variation that is not explained by the linear model.

To minimize ε and achieve an optimal goodness of fit, we adopted the least squares algorithm throughout the study, the goodness of fit being measured by the coefficient of determination, R^2. The linear regressions obtained for each species-gear combination were then applied to the *LFM* of each species, to identify the theoretical *MS* that would achieve $L50 \geq LFM$.

The information gathered from the literature review allowed obtaining the mean *SF* for each species (i.e. $L50 \div MS$). The ANOVA test was used, when possible, to assess the difference between the mean *SF* values obtained with different mesh configurations. Using the *SF*, a simple conversion $L50 = SF \times MS$ allowed modelling for each species a rough estimate of *L50* resulting from the adoption of different meshes and mesh geometries (i.e. 40, 50, 60, 70 and 75 mm *DM*, 40, 50 and 55 mm *SM*), given that the statistics do not evidence a clear effect of *TD* and codend rigging.

For each species, the relationship between the ratios of *L50* to *MCRS* and *L50* to *LFM* were represented graphically in density diagrams (selectivity indicator graph). If the *MCRS* of a given species was not reported in European Regulation 1967/2006 (EC, 2006), only its *LFM* was used. The diagrams allowed evaluating whether a specific net with given mesh characteristics retains mature or immature individuals above or under the *MCRS*. From a strictly technological and ecological viewpoint, the net should ideally catch mature individuals above the *MCRS*. However, if the gear catches mature individuals under the *MCRS*, the *MCRS* for that species is inappropriate: the selectivity of the net should be improved and the *MCRS* redefined, to prevent discarding. Finally, if the gear catches immature individuals above the *MCRS*, the *MCRS* for that species should rapidly be revised.

Results

The initial search produced more than 120 records regarding trawl selectivity in Spain, France, Italy, Tunisia, Morocco, Greece, Turkey, Cyprus, Egypt and Israel. When studies were mentioned in more than one document, e.g. contract reports, theses and peer-reviewed publications, only the latter records were considered. This left 93 references addressing bottom trawl selectivity in the Mediterranean Sea. Given the multi-species nature of the Mediterranean bottom trawl fishery, all species mentioned in the records were listed, totalling 742 records and 65 species (Supplementary Table S2). Where the selectivity parameters were available, they were related to the *LFM*. The *LFM* of the main species described in this overview is reported in Supplementary Table S1. The information thus collected demonstrates that, of the 65 species analysed, only 17 have the *MCRS* based on the current regulation; for 59% of these species, the *MCRS* is well below the *LFM*.

Altogether, the 93 papers were published in the past 55 years (1966 - 2021) covering 17 Geographical Sub-Areas (*GSAs*); most records were published from 2002 to 2005 and most addressed codend mesh selectivity. The main goal of the studies conducted in the 1970s and 1980s was to measure the length and age at first capture of the main commercial species for stock evaluation, rather than to test the possible benefits of increasing *MS*. Earlier selectivity studies addressed exclusively *DM* codends, because *SM* codends did not become legal in the EU until 2006 (EC, 2006). Most studies of *SM* codends and other devices date from 2002 onwards. The majority of studies were performed in *GSAs* 17, 22 and 24 and they largely used the covered codend technique (Wileman *et al.,* 1996).

Most studies analysed the influence of *MS* and mesh geometry on Mediterranean bottom trawl selectivity. They investigated *DM* more often than *SM* codends and seldom examined hexagonal mesh or *T90* codends (where diamond netting is turned through 90°). Most selectivity studies investigated common commercial species such as red mullet (*Mullus barbatus*), hake (*Merluccius merluccius*), deep-water rose shrimp (*Parapenaeus longirostris*), annular seabream (*Diplodus annularis*) and common pandora (*Pagellus erythrinus*) and most of them used a 40 mm *DM*. The way mesh size was reported differed among studies, since the earlier works reported only the nominal *MS* (*NMS*) and rarely the measured *MS* (*MeasMS*, the inside *MS* or, more correctly, mesh opening), whereas the more recent papers often mentioned both values; in some cases the difference between the two parameters was as high as 6 mm. Reporting only the *NMS* (or failing to specify which parameter is being reported) can be misleading, especially if the study aims to evaluate the relationship between *MS* and *L50* and/or *SR*.

Data analysis showed that *MS* and mesh geometry are the technical measures exerting the strongest influence on codend selectivity (Figs. 1-3); in contrast, the effect of codend circumference and *TD* on the selection of most species described in the records was unclear, probably due to the limited number of studies (Figs. 4,5). A greater codend circumference (Fig. 4) and *TD* (Fig. 5) seem to adversely affect the selection of red mullet and common pandora, although data analysis did not support these observations (except for red mullet vs *TD*), possibly due to the limited data available for the two species and/or to the wide confidence intervals.

Table 1 reports the results of the regressions between *L50* and *SR* with *MS*, *TD* or the rigging ratio for the *DM* codends (for which there was an adequate dataset) for the selected fish, mollusc and crustacean species. They show that most fish and crustaceans are the species most heavily affected by *MS* increases in *DM* nets, whereas *TD* and the rigging ratio exert a limited effect.

The diagrams illustrating the relationships among the selectivity indicators (Fig. 6) provided useful information for fishery management; in particular, they show a shift of the selectivity indicators for *DM* and *SM* codends towards the lower left quadrant, a clear sign that the nets catch immature individuals under the *MCRS* (note the lower left corner in Fig. 6).

The results obtained by pooling the data of all species are confirmed at the species level (Fig. 7). The diagrams for hake, common pandora, annular seabream, horse mackerel, poor cod, blue whiting and most crustacean species clearly show that the bottom trawl catches individuals under both the *MCRS* and the *LFM*. *SM* codends show slightly greater selectivity for red mullet and Norway lobster, whose cross-sectional body shape fits the *SM* better. The *DM* is more selective for flat fish like Mediterranean scaldfish, as confirmed by the shift of the density diagram towards the upper right panel. Albeit with very few exceptions, *L50* did not seem to be affected by *MS* (Figs. 1-3). In contrast, for a given *MS* the *SM* appeared to be more selective than the *DM*, as clearly demonstrated by *SF* analysis (Table 2). In fact, considering the 25 species for which the data allowed performing the statistical analysis, the *SM* was more selective than the *DM* in 60% of cases, whereas for the others the differences were not significant (Table 2). However, these results may be affected by the limited number of studies addressing the effect of different *SM* sizes, also compared with those investigating *DM* sizes (see Supplementary Table S2). These contrasting results should therefore be interpreted with caution, since they could be affected by the limited number of studies analysed.

Table 3 shows the hypothetical selectivity scenario for each species and mesh configuration obtained by applying this mean *SF*. Comparison of the values obtained with the same mesh sizes (i.e *DM40* vs *SM40* and *DM50* vs *SM50*) shows that the *SM* is generally more selective than the *DM* (Table 3). However, the *DM* seems to be more selective for three flat fish species (*Arnoglossus laterna*, *Citharus linguatula* and *Lepidorhombus boscii*) and for *Octopus vulgaris* (although for the two latter species the difference between the two meshes is minimal). How-

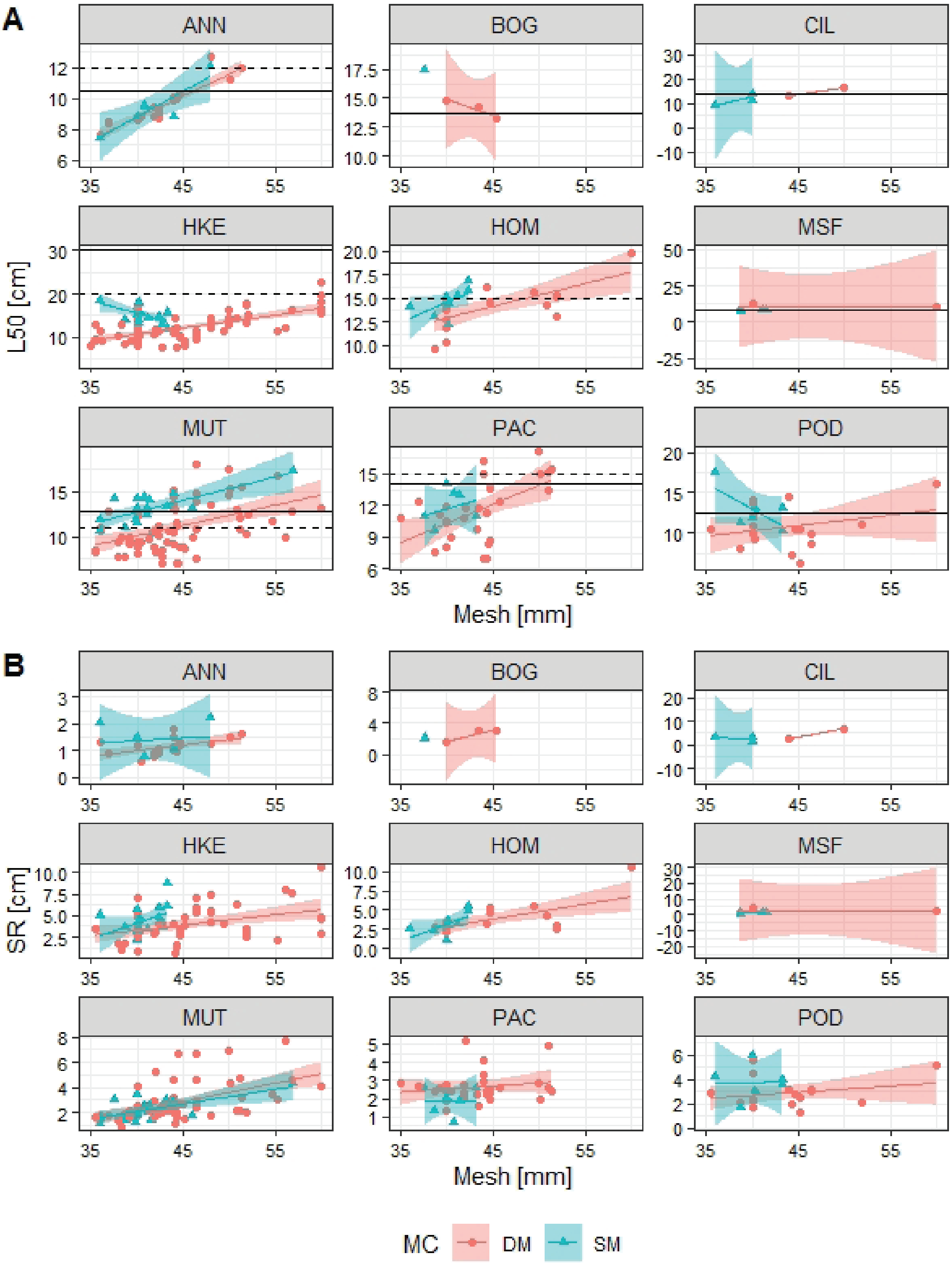

Fig. 1: Relationship of mesh size with *L50* (A) and SR (B) in diamond mesh (*DM*) and square mesh (*SM*) codends for the most important fish species targeted in the Mediterranean Sea. Red line (*DM*) and blue line (*SM*): linear regressions; red (*DM*) and blue (*SM*) shadowed areas: confidence intervals; the solid black line represents the *LFM*; the dotted line represents the *MCRS*. Species are identified by their FAO code (see Table S2). *MC*: mesh configuration.

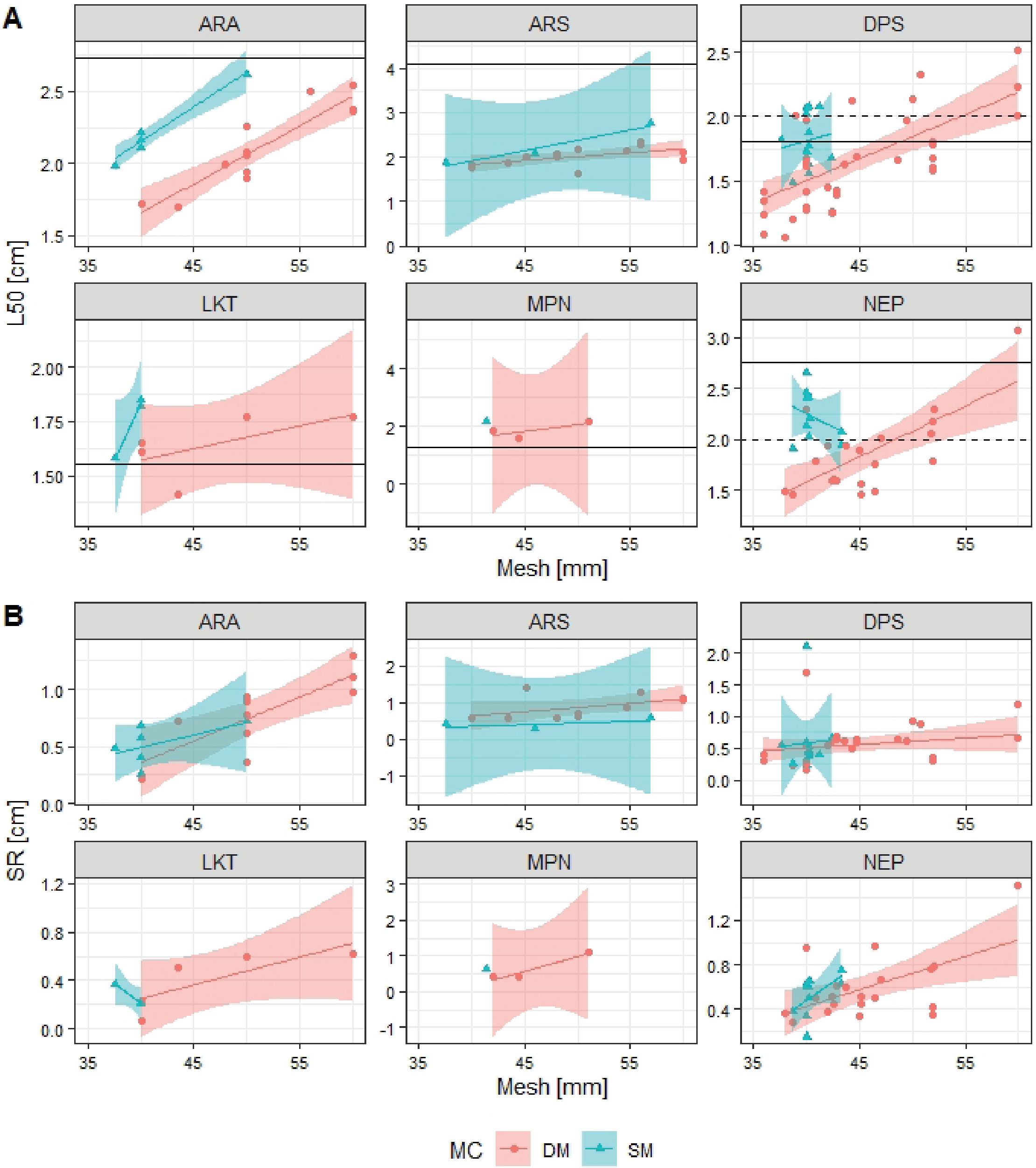

Fig. 2: Relationship of mesh size with *L50* (A) and *SR* (B) in diamond mesh (*DM*) and square mesh (*SM*) codends for the most important crustacean species targeted in the Mediterranean Sea. Red line (*DM*) and blue line (*SM*): linear regressions; red (*DM*) and blue (*SM*) shadowed areas: confidence intervals; the solid black line represents the *LFM*; the dotted line represents the *MCRS*. Species are identified by their FAO code (see Table S2). *MC*: mesh configuration.

ever, in the current regulatory framework (Resolution GFCM/31/2007/3) it is not always clear which of the two legal codend meshes (*SM40* or *DM50*) is more suitable, since the *SM40* seems to perform better for some species and the *DM50* for others. In general, the *SM* seems to be more selective for species with a roughly circular body cross-section (round fish). However, the selectivity of the two legal codends is in most cases lower than the *LFM* obtained from the review. In fact, as regards *DM50*, *L50* is lower than the *LFM* in 68% of the species, whereas with *SM40* this is true in 64% of cases. In addition, of the 9 species with an *MCRS* and for which selectivity has been determined with both legal codends, the *L50* is above the *MCRS* only for *M. barbatus* and *Nephrops norvegicus*, whereas for the other species *L50* is usually under the *MCRS* (see Supplementary Tables S1, S2). Therefore, a

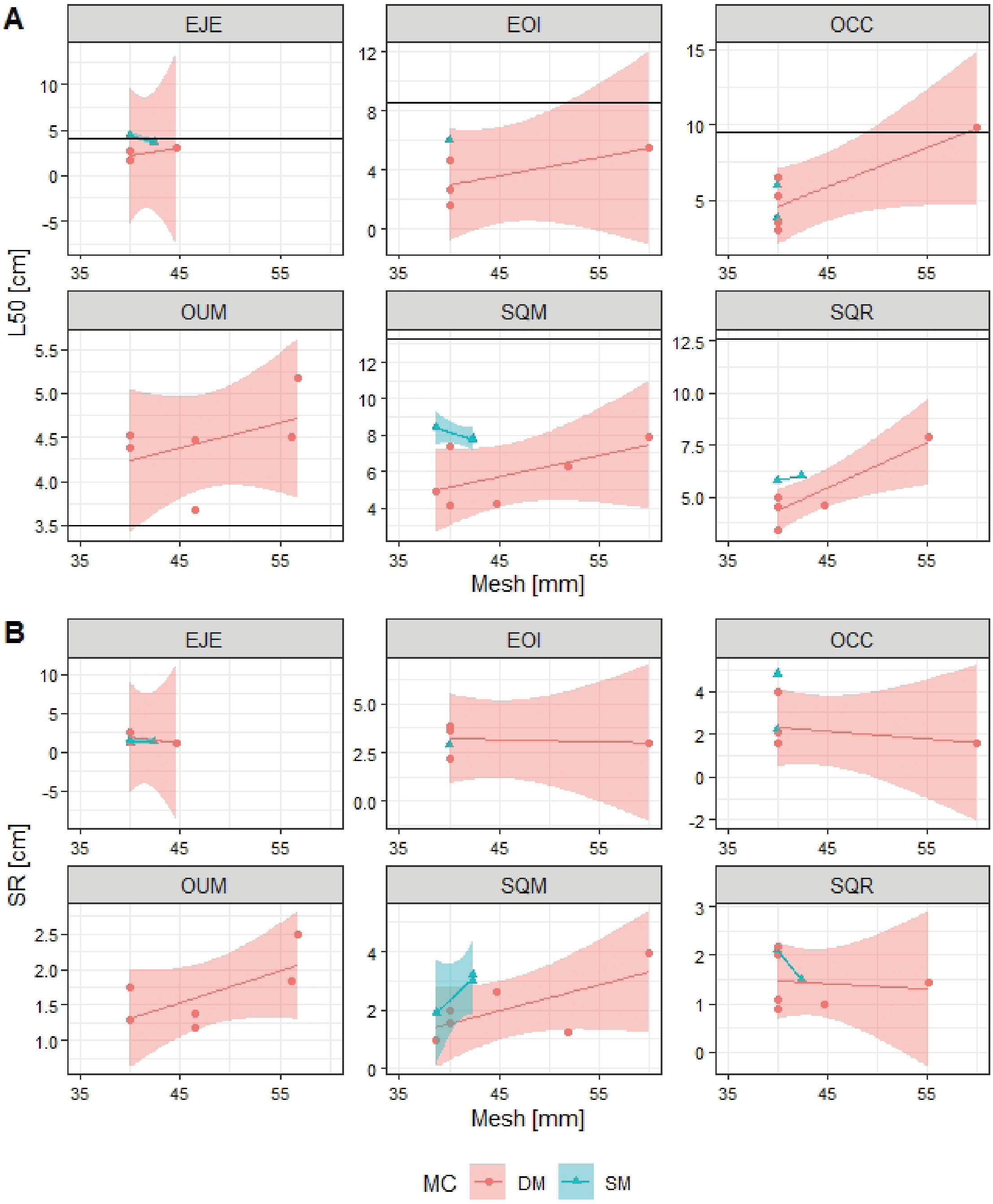

Fig. 3: Relationship of mesh size with *L50* (A) and *SR* (B) in diamond mesh (*DM*) and square mesh (*SM*) codends for the most important cephalopod species targeted in the Mediterranean Sea. Red line (*DM*) and blue line (*SM*): linear regressions; red (*DM*) and blue (*SM*) shadowed areas: confidence intervals; the solid black line represents the *LFM*. Species are identified by their FAO code (see Table S2). *MC*: mesh configuration.

steep increase in mesh opening would be required to fit both *L50* and *MCRS* to the *LFM*. In a hypothetical scenario based solely on the *SF* calculated using exclusively the data, *MS* and mesh geometry obtained from our review (Table 3), the current legal *MSs* are highly unlikely to ensure the capture of specimens above the *LFM*, whereas the results obtained for *SM* codends are slightly better. In contrast, the data indicate that a considerable *MS* increase would be required to ensure the escape of fish under the *LFM*.

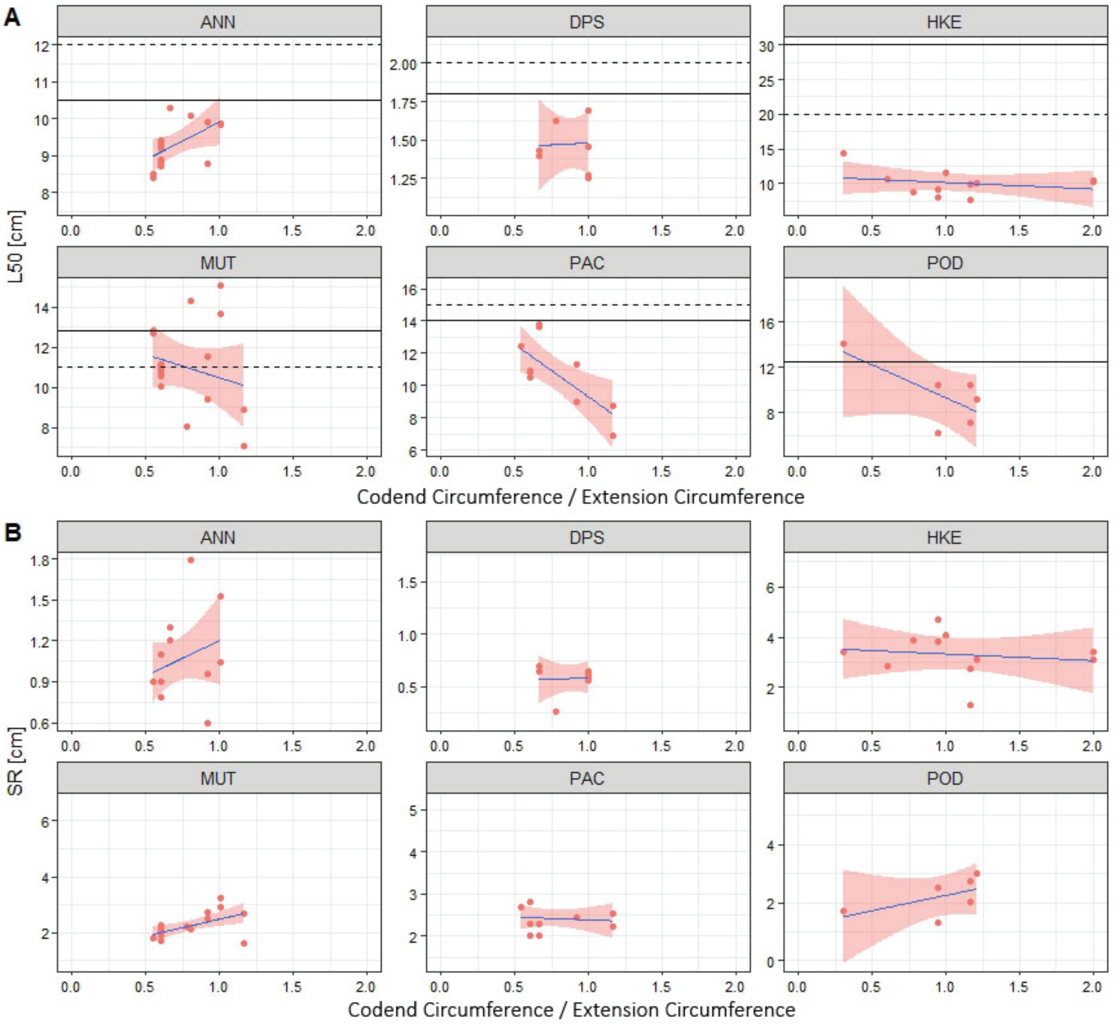

Fig. 4: Relationship of the codend rigging ratio (codend circumference/extension circumference) with *L50* (A) and *SR* (B) in diamond mesh codends for the most important species targeted in the Mediterranean Sea. Red shadowed area: confidence interval; solid blue line: linear regression; the solid black line represents the *LFM*; the dotted line represents the *MCRS*. Species are identified by their FAO code (see Table S2). Only the species for which an adequate amount of data was available were considered.

Discussion

In the Mediterranean Sea, where more than 75% of the fish stocks assessed are considered as overfished (FAO, 2020), a thorough knowledge of net selection properties is critical to evaluate fishery sustainability.

When reviewing species selectivity data, the key parameters are the *MCRS* (which may differ among countries) and the *LFM*. Our study indicates that for some species the *MCRS* set by EU regulations (EC, 2006) is well below the *LFM*. This is a common problem of Mediterranean fishery legislation, where the technical measures (chiefly the *MCRS* and *MMS*) try to balance the multi-species nature of fisheries and fishers' profits. Our data agree with those of earlier studies, showing that the minimum landing sizes set for Mediterranean fisheries are ecologically inadequate and do not respect the life cycle of species (Stergiou *et al.,* 2009).

In this, diagrams illustrating the relationships among the selectivity indicators were developed to establish whether the bottom trawls catch immature individuals of some major species. Data analysis confirmed the low size and species selectivity of bottom trawls, which fail to spare specimens under the *MCRS* of several commercially important species. The ecological purpose of the *MCRS* and *MMS* is to avoid catching juveniles until they are large enough to spawn (Beverton & Holt, 1957); from an economic standpoint, this means that juveniles are given time to grow to an economically useful size before they are harvested. Despite the basic nature of this notion, the determination of a legal *MS* can involve practical difficulties and management problems (Beddington & Rettig, 1984). A common objection to increasing it is that several years may be needed to recoup the losses,

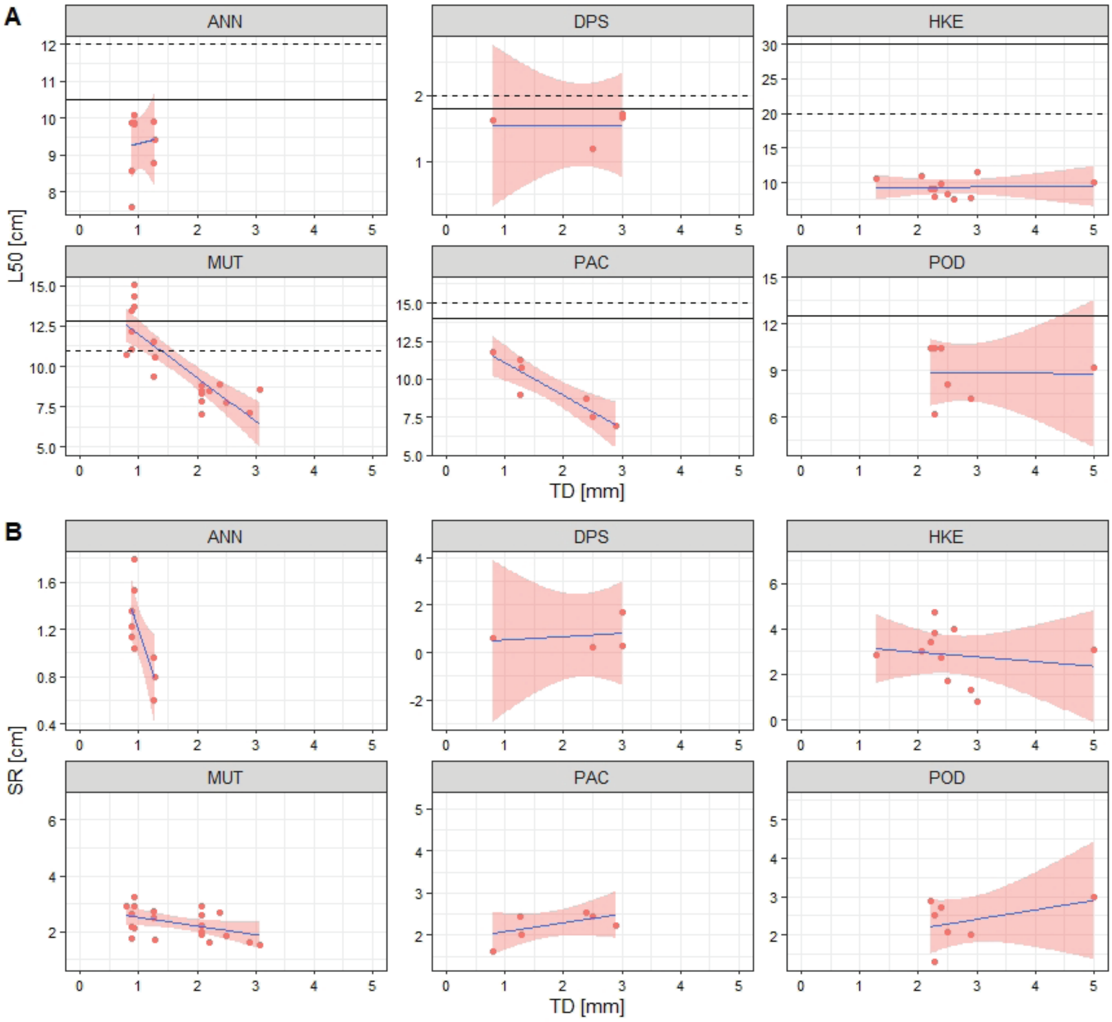

Fig. 5: Relationship between twine diameter (*TD*) and *L50* (A) and *SR* (B) in diamond mesh codends for the most important species targeted in the Mediterranean Sea. Red shadowed area: confidence interval; solid blue line: linear regression; the solid black line represents the *LFM*; the dotted line represents the *MCRS*. Species are identified by their FAO code (see Table S2). Only the species for which an adequate amount of data was available were considered.

which are immediate. The GFCM Member Countries have adopted an *MS* of at least *SM40* in the codend as per Resolution GFCM/31/2007/3 (GFCM, 2007). According to our data, for any given *MS*, *SM* codends are more selective than *DM* codends. However, *SM* codends have proved highly selective for round fish in demersal trawls, whereas *DM* codends seem to be more selective for flat fish, most likely due to their cross-sectional body shape. Our data show that the gears targeting flat fish, such as *rapido* trawls in the Adriatic Sea (Pranovi *et al.,* 2000), should only mount *DM* codends.

Data analysis demonstrated that the *L50* obtained using the legal *MS* in the codend (*SM40* or *DM50*) is well below the *LFM* of several species. This means that the *MS* of trawl nets should be substantially increased to avoid catching juveniles of some major species, although this would entail losing adults of other commercial species. Therefore, our data may be of interest to fishery managers and fishing technologists, in that they provide a rough estimate of the *MS* and mesh geometry that would enhance selectivity, even though other parameters such as *TD* and codend circumference (which we considered only for the analysis of *DM*) also exert a slight effect on selectivity.

In their review of 42 European Mediterranean stocks of nine species, Vasilakopoulos *et al.* (2014) have found steadily increasing exploitation rates and shrinking stocks. Overexploitation of hake juveniles was particularly severe, since they were harvested from 0.6 to 1.9 years before maturity. The authors' simulations suggest that urgent measures should be adopted not only to reduce the exploitation rate but, critically, to increase selectivity. The present study demonstrates that the state of overfishing of so many Mediterranean stocks is chiefly due to the poor selectivity of trawls, which capture individuals of

Table 1. Results of the regression analysis for the *DM* codend. Effect of mesh size (*MS*), rigging ratio (codend circumference/extension circumference), twine diameter (*TD*) on the *L50* and *SR* for the main species targeted in the Mediterranean Sea. F: Fisher coefficient. In brackets: the degrees of freedom used to calculate the p-value R^2 are reported only for significant relationships. P-values in bold. CIL: NO TEST means that data were not sufficient for the species. The order of the species is based on their category (fish, crustaceans, cephalopods).

	Species		MS			TD			Rigging ratio		
	FAO Code	Scientific name		R^2	p		R^2	p		R^2	p
L50	ANN	*Diplodus annularis*	F(1,21) = 120.3	0.85	**< 0.001**	F(1,9) = 0.1		0.809	F(1,17) = 5.0		**0.039**
	BOG	*Boops boops*	F(1,3) = 2.1		0.244	-			-		
	CIL	*Citharus linguatula*	NO TEST			-			-		
	HKE	*Merluccius merluccius*	F(1,74) = 72.5	0.5	**< 0.001**	F(1,14) = 0.2		0.708	F(1,16) = 0.4		0.555
	HOM	*Trachurus* spp	F(1,17) = 35.8	0.68	**< 0.001**	-			-		
	MSF	*Arnoglossus laterna*	F(1,3) = 0.9		0.48	-			-		
	MUT	*Mullus barbatus*	F(1,73) = 18.2	0.2	**< 0.001**	F(1,23) = 19.3	0.46	**< 0.001**	F(1,23) = 2.1		0.157
	PAC	*Pagellus erythrinus*	F(1,31) = 13.1	0.3	**0.001**	F(1,8) = 3.5		0.097	F(1,11) = 3.1		0.105
	POD	*Trisopterus minutus*	F(1,16) = 2.7		0.119	F(1,7) = 0.01		0.916	F(1,6) = 4.8		0.071
	ARA	*Aristeus antennatus*	F(1,10) = 45.3	0.82	**< 0.001**	-			-		
	ARS	*Aristaeomorpha foliacea*	F(1,11) = 5.7	0.34	**0.036**	-			-		
	DPS	*Parapenaeus longirostris*	F(1,35) = 46.4	0.57	**< 0.001**	F(1,2) = 0.0		0.991	F(1,7) = 0.3		0.623
	LKT	*Plesionika martia*	F(1,3) = 1.5		0.303	-			-		
	MPN	*Metapenaeus monoceros*	F(1,1) = 1.8		0.411	-			-		
	NEP	*Nephrops norvegicus*	F(1,16) = 18.6	0.54	**< 0.001**	-			-		
	EJE	*Sepia elegans*	F(1,1) = 0.6		0.577	-			-		
	EOI	*Eledone cirrosa*	F(1,2) = 2.0		0.292	-			-		
	OCC	*Octopus vulgaris*	F(1,3) = 8.5		0.061	-			-		
	OUM	*Alloteuthis media*	F(1,4) = 1.1		0.347	-			-		
	SQM	*Illex coindetii*	F(1,3) = 1.5		0.303	-			-		
	SQR	*Loligo vulgaris*	F(1,3) = 0.02		0.891	-			-		

Continued

Table 1 continued

	Species		MS			TD			Rigging ratio		
	FAO Code	Scientific name		R^2	p		R^2	p		R^2	p
SR	ANN	*Diplodus annularis*	F(1,21) = 10.1	0.32	**0.005**	F(1,9) = 2.4		0.153	F(1,17) = 2.4		0.137
	BOG	*Boops boops*	F(1,1) = 27.0		0.121	-			-		
	CIL	*Citharus linguatula*	NO TEST			-			-		
	HKE	*Merluccius merluccius*	F(1,46) = 11.7	0.2	**0.001**	F(1,12) = 0.6		0.451	F(1,16) = 0.04		0.844
	HOM	*Trachurus* spp	F(1,17) = 26	0.61	**< 0.001**	-			-		
	MSF	*Arnoglossus laterna*	F(1,3) = 0.08		0.8	-			-		
	MUT	*Mullus barbatus*	F(1,63) = 33.5	0.35	**< 0.001**	F(1,21) = 1.2		0.278	F(1,23) = 9.8	0.3	**0.005**
	PAC	*Pagellus erythrinus*	F(1,29) = 1.8		0.195	F(1,6) = 1.4		0.278	F(1,11) = 0.05		0.836
	POD	*Trisopterus minutus*	F(1,16) = 3.2		0.095	F(1,7) = 0.3		0.617	F(1,6) = 4.3		0.084
	ARA	*Aristeus antennatus*	F(1,8) = 15.4	0.65	**0.005**	-			-		
	ARS	*Aristaeomorpha foliacea*	F(1,8) = 2.5		0.146	-			-		
	DPS	*Parapenaeus longirostris*	F(1,27) = 8.1	0.23	**0.009**	F(1,2) = 0.1		0.782	F(1,7) = 0.1		0.729
	LKT	*Plesionika martia*	F(1,3) = 5.9		0.092	-			-		
	MPN	*Metapenaeus monoceros*	F(1,1) = 21.3		0.136	-			-		
	NEP	*Nephrops norvegicus*	F(1,16) = 19.7	0.65	**< 0.001**	-			-		
	EJE	*Sepia elegans*	F(1,1) = 0.5		0.062	-			-		
	EOI	*Eledone cirrosa*	F(1,2) = 0.04		0.859	-			-		
	OCC	*Octopus vulgaris*	F(1,3) = 0.3		0.614	-			-		
	OUM	*Alloteuthis media*	F(1,4) = 3.9		0.119	-			-		
	SQM	*Illex coindetii*	F(1,3) = 23.5	0.89	**0.017**	-			-		
	SQR	*Loligo vulgaris*	F(1,3) = 0.6		0.508	-			-		

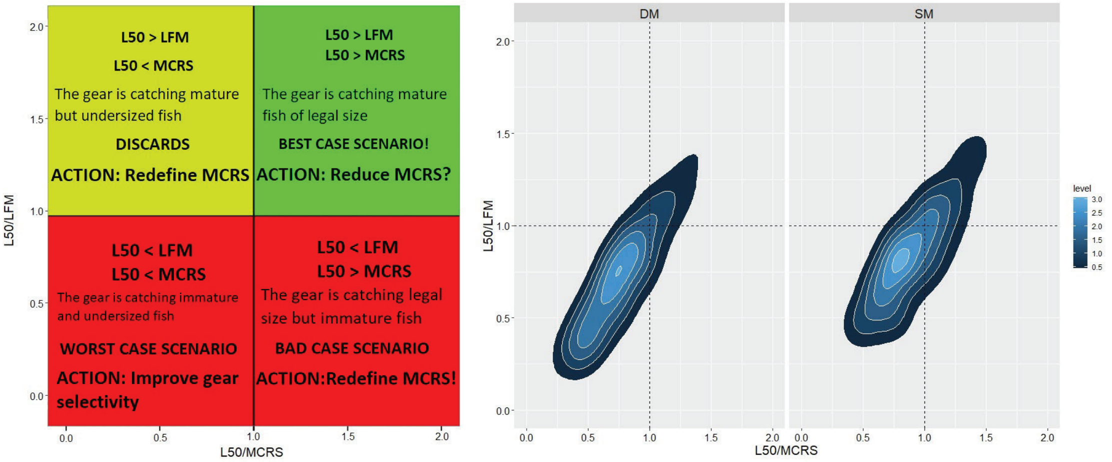

Fig. 6: Density diagrams showing the relationships among the selectivity indicators. a) Diagram based on theoretical data; b) diagram based on experimental data.

major commercial species well before they have reached the reproductive stage. Vasilakopoulos *et al.* (2014) also reported that selectivity improvement in the Mediterranean has a greater potential to benefit stocks of long-lived demersal species than of short-lived small pelagic ones. However, the models applied in our study demonstrate that larger codend meshes enhance selectivity only for some species, lending support to the view that in Mediterranean multi-species fisheries codend selectivity alone may be insufficient to reduce unwanted catches and discards. Other devices, combined with proper codends, should be adopted to enhance size and species sorting.

Finding ways to preserve fishery resources and the marine environment, to minimize the biological effects of bycatch and to promote sustainable fisheries in the Mediterranean requires further investigation of fishing gears and their impacts and the urgent development of techniques ensuring greater size and species selection (Sala & Lucchetti, 2010; Brčić *et al.,* 2015; Lucchetti *et al.,* 2016). Yet, too few studies have addressed alternative gears and gear modifications (also known as bycatch reduction devices; BRDs), such as *T90* codends (Tokaç *et al.,* 2014; Dereli & Aydin, 2016; Dereli *et al.,* 2016; Petetta *et al.,* 2020a), hexagonal mesh codends (Aydin & Tosunoğlu, 2009, 2010; Tosunoğlu *et al.,* 2009), *SM* panels (Metin *et al.,* 2005; Kaykaç *et al.,* 2009; Tokaç *et al.,* 2009; Özbilgin *et al.,* 2015; Brčić *et al.,* 2017; Bonanomi *et al.,* 2020) and sorting grids (Sardà *et al.,* 2004, 2005, 2006; Bahamon *et al.,* 2007; Massutí *et al.,* 2009; Özvarol, 2016; Quetglas *et al.,* 2017) in the Mediterranean. Therefore, despite promising results, data are too limited to draw general conclusions.

T90 codends, which have mainly been tested in Turkish waters against conventional *DM* codends, have shown increased selectivity for the species investigated, even though this effect was not always evident, a fact that the researchers attributed to differences in fish body shape (Tokaç *et al.,* 2014). Petetta et al. (2020a) have documented that a 54 mm *T90* codend can exclude undersized hake specimens, whose average *L50* was above the *MCRS.*

Hexagonal mesh codends have proved to be more size-selective than common *DM* codends for shrimp (e.g. deep-water rose shrimp; Aydin & Tosunoğlu, 2009) and cephalopods (e.g. broadtail shortfin squid; Tosunoğlu *et al.,* 2009), whereas the results were less clear for fish (Aydin & Tosunoğlu, 2010).

SM panels commonly consist of a "window" of *SM* netting installed on the upper part or the sides of *DM* codends or on the extension piece, immediately ahead of the codend, to allow the escape of non-target species and sizes. Key parameters are *MS* and window size and location. *SM* panels attached to the top side of a bottom trawl, tested in the Mediterranean, did not significantly enhance selectivity compared with a traditional trawl, and *SM* codends showed an average better selection performance than the panel; in contrast, a 70 mm *SM* panel attached on the lateral sides of the extension piece of a commercial trawl net significantly improved the escape probability of red mullet, despite involving a loss of the marketable fraction (Bonanomi *et al.,* 2020). In summary, although *SM* panels show some promise, the available data are too limited to draw conclusions.

A sorting grid is a frame fitted into the extension of the trawl, immediately in front of the codend, supporting spaced bars made of aluminium, steel or plastic. Its design and material, the space between the bars, its installation, operational angle and the position of the exit hole (top or bottom) strongly depend on the purpose for which the grid is used. Some, such as Turtle Excluder Devices (*TEDs*; Lucchetti *et al.,* 2019; Vasapollo *et al.,* 2019) and grids for excluding sharks (Brčić *et al.,* 2015), have specifically been tested to avoid the catch of large individuals of bycatch species, with promising results. Other grids have been designed to reduce the capture of undersized individuals of some target species (i.e. Juvenile and Trash Excluder Devices; *JTEDs*). For instance, testing by Vitale et al. (2018) of different *JTEDs,* to reduce unwanted catches of undersized deep-water shrimp and European hake in the Strait of Sicily, also involved significant commercial losses.

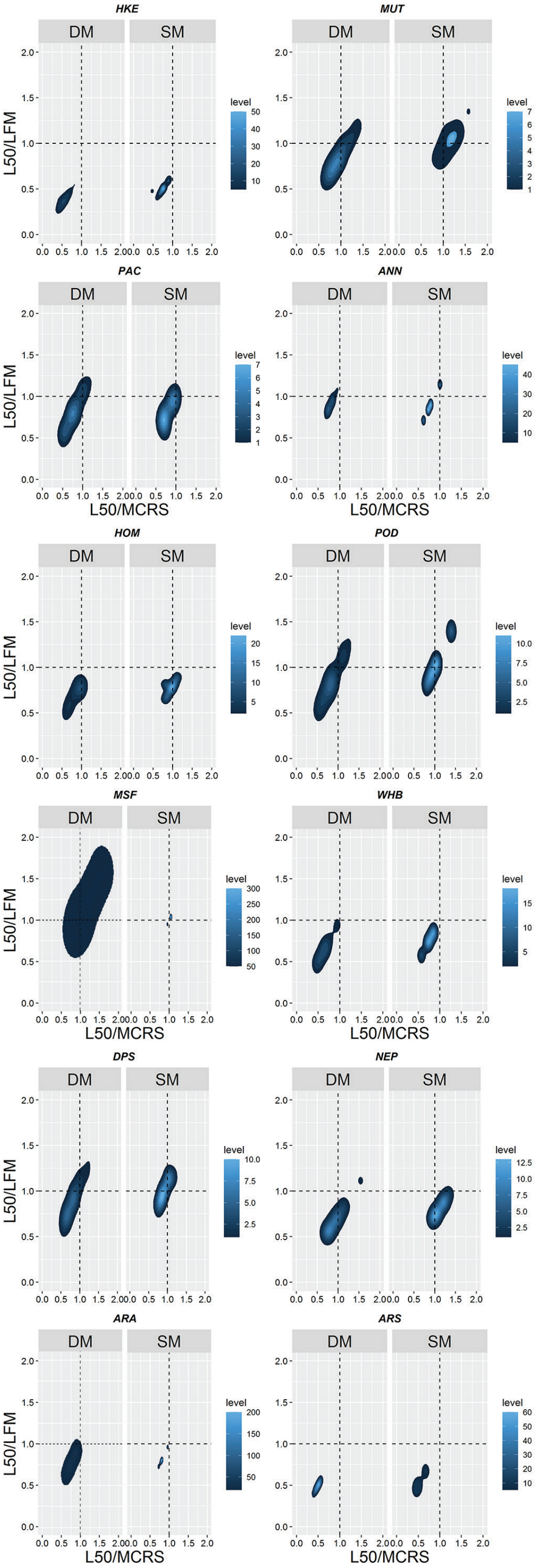

Fig. 7: Diagrams showing the relationships among the selectivity indicators for 12 key species, identified by their FAO code (see Table S2).

Table 2. Mean selection factor (*SF*) and standard deviation obtained from data analysis. The Difference is the one between *SM* (square mesh) and *DM* (diamond mesh). (+): SM > DM; (-): SM < DM. *: p < 0.05; **: p < 0.01; ***: p < 0.001.

Species	DM			SM			Difference	p
Alloteuthis media	0.95	±	0.14					No Test
Argentina sphyraena	3.22	±	0.55					No Test
Aristaeomorpha foliacea	0.41	±	0.04	0.48	±	0.02	+	0.019*
Aristeus antennatus	0.41	±	0.02	0.54	±	0.01	+	< 0.001***
Arnoglossus laterna	2.3	±	0.53	2.01	±	0.03		0.308
Aspitrigla cuculus				3.03	±	0.0		No Test
Boops boops	3.4	±	0.4	4.66	±			No Test
Buglossidium luteum				2.58	±	0.02		No Test
Caelorinchus caelorhincus	0.69	±	0.09					No Test
Chelidonichthys lastoviza	1.18	±	0.0	1.83	±	0.0		No Test
Chlorophthalmus agassizi	2.88	±	0.25					No Test
Citharus linguatula	3.16	±	0.22	2.99	±	0.48		0.686
Dentex macrophthalmus	2.39	±	0.27					No Test
Dentex maroccanus	2.18	±	0.11	2.5	±	0.0		No Test
Diplodus annularis	2.23	±	0.12	2.24	±	0.18		0.905
Eledone cirrosa	0.78	±	0.32	1.5	±	0.0		No Test
Engraulis encrasicolus	3.96	±	0.52					No Test
Galeus melastomus	3.09	±	0.3	5.58	±	0.04	+	0.007**
Geryon longipes				0.63	±	0.0		No Test
Helicolenus dactylopterus	1.81	±	0.31	2.75	±	0.03	+	0.001**
Illex coindetii	1.28	±	0.36	1.94	±	0.2	+	0.028*
Lepidorhombus boscii	2.5	±	0.07	2.35	±	0.21		0.307
Lepidotrigla cavillone	1.86	±	0.09	2.4	±	0.0		No Test
Loligo vulgaris	1.1	±	0.17	1.44	±	0.02	+	0.047*
Merlangius merlangus	2.5	±	0.53					No Test
Merluccius merluccius	2.72	±	0.51	3.72	±	0.55	+	< 0.001***
Metapenaeus monoceros	0.41	±	0.04	0.53	±	0.0		No Test
Micromesistius poutassou	3.25	±	0.92	4.35	±	0.7	+	0.003**
Mullus barbatus	2.55	±	0.51	3.17	±	0.32	+	< 0.001***
Mullus surmuletus	2.16	±	1.46	3.05	±	0.0		No Test
Nemipterus randalli	1.98	±	0.58	3.46	±	0.0		No Test
Nephrops norvegicus	0.41	±	0.06	0.55	±	0.08	+	< 0.001***
Octopus salutii	1.14	±	0.0					No Test
Octopus vulgaris	1.24	±	0.41	1.23	±	0.38		0.979
Pagellus acarne	2.95	±	0.17	2.96	±	0.42		0.930
Pagellus erythrinus	2.71	±	0.53	2.98	±	0.38		0.258
Pagrus pagrus	2.57	±	0.0					No Test
Parapenaeus longirostris	0.38	±	0.06	0.45	±	0.06	+	0.003**
Phycis blennoides	2.74	±	0.31	3.77	±	0.21	+	< 0.001***
Plesionika martia	0.36	±	0.05	0.45	±	0.02	+	0.031*
Sardina pilchardus	3.92	±	0.28					No Test
Saurida undosquamis	4.54	±	1.73	4.99	±	0.92		0.650
Scorpaena notata				2.43	±	0.0		No Test

Continued

Table 2 continued

Species	DM			SM			Difference	p
Scorpaena scrofa				2.08	±	0.0		No Test
Scyliorhinus canicula	4.7	±	0.0	7.18	±	0.0		No Test
Sepia elegans	0.55	±	0.21	1.1	±	0.03	+	0.016*
Sepia orbignyana	0.67	±	0.0	0.88	±	0.04		No Test
Sepietta oweniana	0.55	±	0.0					No Test
Serranus cabrilla	2.33	±	0.0	3.53	±	0.0		No Test
Serranus hepatus	2.19	±	0.08					No Test
Spicara flexuosa	3.36	±	0.0					No Test
Spicara maena	3.24	±	0.18	3.86	±	0.46		0.066
Spicara smaris	3.11	±	0.39	4.28	±	0.0		No Test
Sprattus sprattus	3.28	±	0.66					No Test
Squilla mantis	1.84	±	0.0					No Test
Trachinus draco	3.33	±	0.0	4.53	±	0.0		No Test
Trachurus spp	3.19	±	0.41	3.75	±	0.0		No Test
Triglidae				3.51	±	0.0		No Test
Trisopterus minutus	2.5	±	0.61	3.22	±	0.86	+	0.030*
Upeneus moluccensis	3.05	±	0.39	4.17	±	0.26		0.078
Upeneus spp	2.61	±	1.23	3.68	±	0.0		No Test

Some grids successfully sorted shrimp and Norway lobster from other species in EU waters (Ungfors *et al.,* 2013). They could therefore be adopted in Mediterranean fisheries targeting *N. norvegicus* and *A. folicaea* and *Aristeus antennatus*. However, further investigation is required to assess the effectiveness, in improving size and species selection, of the various grid types tested in the Mediterranean Sea (Vitale *et al.,* 2018; Lucchetti *et al.,* 2019; Vasapollo *et al.,* 2019).

The economic consequences of introducing gear modifications also need be considered, since they may constitute the foremost constraint. However, since bycatch often costs time and money (Lucchetti *et al.,* 2019), the introduction and adaptation of *BRDs* and of more selective gears should be achieved gradually, in close collaboration with the fishing industry (Virgili *et al.,* 2018). Indeed, industry participation in *BRD* development itself would be highly useful and result in greater compliance. Clearly, fishing trials are also essential to optimize their setup and minimize short-term economic losses (Lucchetti *et al.,* 2016). Therefore, a thorough discussion of these topics, which are fairly novel for Mediterranean Sea fisheries, should be encouraged and its results and experiences shared among fishing technologists.

Although the discard rates of Mediterranean bottom trawl fisheries are reported to be very high (Tsagarakis *et al.,* 2014), there are few studies on the relationship between selectivity and discards. Mytilineou *et al.* (2018, 2021b, a) described how the overall discard probability of a given species results from trawl net selectivity plus the size selection operated on deck by fishers. Using a selection model that simultaneously describes escape, discard rate and landing probability, the authors showed that the *SM40* codend is more suitable for the sustainability of the main commercial species than *DM* codends, since it produces much fewer discards and less economic losses.

Little information is available on the survival probability of the individuals escaped from a trawl net. Metin *et al.* (2004) and Düzbastilar et al. (2010, 2016) collected escapees using covers, which were detached after a short tow, fixed to the sea bottom and monitored by divers for a few days. Survival probability depended on species, fish size and water temperature, and was higher in red mullet (Metin *et al.,* 2004) than in flat fish (Düzbastilar *et al.,* 2016). A short-term survival assessment of different discarded species by Tsagarakis *et al.* (2018), who monitored them in water tanks after sorting on board, mortality differed among species and showed strong seasonal variation, since higher water and air temperature severely affected survival.

In addition to their adverse effects on population structure and stock abundance, bottom trawls exert strong environmental impacts both in terms of habitat destruction – by scraping or ploughing into the bottom (Lucchetti & Sala, 2012; Lucchetti *et al.,* 2017), thus affecting benthic communities (Brambati & Fontolan, 1990; Giovanardi *et al.,* 1998; Smith *et al.,* 2000, 2007; Morello *et al.,* 2005) – and in terms of carbon emissions (Sala *et al.,* 2011; Gabiña *et al.,* 2016). In a study where they mapped the pressure of EU trawlers on benthic habitats from logbook statistics and vessel monitoring system data, Eigaard et al. (2016) showed that the Mediterranean is one of the most severely impacted seas in the world. High fishing pressure and low gear selectivity make bottom trawling the main driver of the decline of demersal stocks in this basin (Cardinale *et al.,* 2017). Modifications that enhance

Table 3. Hypothetical *L50* scenario based exclusively on the mean Selection Factor (*SF*) calculated using the data and mesh size and geometry obtained from the review. *LFM*: length at first maturity (from the review); *DM40, DM50, DM60, DM70, DM75*: 40, 50, 60, 70 and 75 mm diamond mesh, respectively; *SM40, 50, 55*: 40, 50 and 55 mm square mesh, respectively. Grey columns: codends complying with Resolution GFCM/31/2007/3 (SM40 and DM50). In bold: L50 values that prevent catching specimens under the *LFM*; the column where each bold value is found indicates the corresponding mesh opening.

Species	*LFM*	*DM40*	*DM50*	*DM60*	*DM70*	*DM75*	*SM40*	*SM50*	*SM55*
Alloteuthis media	3.1	**3.79**	4.74	5.69	6.64	7.11			
Argentina sphyraena	NA	12.89	16.12	19.34	22.56	24.18			
Aristaeomorpha foliacea	4.1	1.62	2.03	2.43	2.84	3.04	1.91	2.38	2.62
Aristeus antennatus	2.7	1.65	2.06	2.47	**2.88**	3.09	2.15	**2.68**	2.95
Arnoglossus laterna	11.6	9.22	**11.52**	13.82	16.13	17.28	8.04	10.05	**11.06**
Aspitrigla cuculus	15.6					0.00	12.12	**15.15**	16.67
Boops boops	13.2	**13.60**	17.00	20.40	23.80	25.50	**18.64**	23.30	25.63
Buglossidium luteum	7.2						**10.33**	12.92	14.21
Coelorinchus caelorhincus	16.2	2.76	3.45	4.14	4.83	5.18			
Chelidonichthys lastoviza	16.1	4.72	5.90	7.08	8.26	8.85	7.32	9.15	10.07
Chlorophthalmus agassizi	10.8	**11.52**	14.40	17.28	20.16	21.60			
Citharus linguatula	14	12.62	**15.78**	18.94	22.09	23.67	11.97	**14.96**	16.45
Dentex macrophthalmus	11.3	9.57	**11.97**	14.36	16.75	17.95			
Dentex maroccanus	14.8	8.73	10.91	13.09	**15.28**	16.37	10.00	12.51	13.76
Diplodus annularis	10.5	8.91	**11.14**	13.37	15.60	16.72	8.95	**11.18**	12.30
Eledone cirrosa	8.9	3.13	3.91	4.70	5.48	5.87	6.00	7.50	8.25
Engraulis encrasicolus	8-12	**15.84**	19.80	23.76	27.72	29.70			
Galeus melastomus	45.4	12.36	15.45	18.54	21.63	23.18	22.30	27.88	30.66
Geryon longipes	NA						2.52	3.15	3.47
Helicolenus dactylopterus	18	7.24	9.05	10.86	12.67	13.58	10.99	13.73	15.11
Illex coindetii	12-15	5.14	6.42	7.70	8.99	9.63	7.77	9.72	10.69
Lepidorhombus boscii	12.2	10.01	**12.52**	15.02	17.52	18.78	9.41	11.77	**12.94**
Lepidotrigla cavillone	14.5	7.43	9.28	11.14	13.00	13.93	9.60	12.00	13.20
Loligo vulgaris	12-16	4.41	5.51	6.61	7.71	8.27	5.74	7.18	7.89
Merlangius merlangus	24.5	9.98	12.48	14.97	17.47	18.71			
Merluccius merluccius	30.3	10.86	13.58	16.29	19.01	20.36	14.88	18.60	20.46
Metapenaeus monoceros	NA	1.63	2.04	2.44	2.85	3.05	2.12	2.65	2.91
Micromesistius poutassou	21	13.00	16.25	19.50	**22.75**	24.37	17.39	**21.73**	23.91
Mullus barbatus	12.8	10.18	**12.73**	15.27	17.82	19.09	**12.67**	15.84	17.42
Mullus surmuletus	15.6	8.64	10.80	12.96	15.12	**16.20**	12.20	15.25	**16.78**
Nemipterus randalli	11.0	7.90	9.88	**11.85**	13.83	14.82	**13.83**	17.29	19.02
Nephrops norvegicus	2.8	1.64	2.05	2.46	**2.87**	3.07	2.20	2.74	**3.02**
Octopus salutii	NA	4.56	5.70	6.84	7.98	8.55			
Octopus vulgaris	9.5	4.96	6.20	7.44	8.68	**9.30**	4.92	6.15	6.77
Pagellus acarne	19.9	11.79	14.74	17.69	**20.64**	22.11	11.85	14.81	16.29
Pagellus erythrinus	17.8	10.83	13.54	16.25	**18.96**	20.31	11.93	14.91	16.40
Pagrus pagrus	31.3	10.28	12.85	15.42	17.99	19.28			
Parapenaeus longirostris	1.8	1.53	**1.91**	2.29	2.67	2.86	**1.82**	2.27	2.50
Phycis blennoides	19.5	10.98	13.72	16.46	19.21	**20.58**	15.08	18.85	**20.74**
Plesionika martia	1.55	1.43	**1.78**	2.14	2.50	2.68	**1.79**	2.23	2.46
Sardina pilchardus	7-12	**15.69**	19.61	23.54	27.46	29.42			
Saurida undosquamis	16.3	**18.15**	22.69	27.23	31.77	34.03	19.95	24.94	27.43

Continued

Table 3 continued

Species	*LFM*	*DM40*	*DM50*	*DM60*	*DM70*	*DM75*	*SM40*	*SM50*	*SM55*
Scorpaena notata	12.5						9.72	12.15	13.37
Scorpaena scrofa	20						8.32	10.40	11.44
Scyliorhinus canicula	48.6	18.80	23.50	28.20	32.90	35.25	28.72	35.90	39.49
Sepia elegans	4.2	2.20	2.75	3.30	3.85	**4.13**	**4.40**	5.50	6.05
Sepia orbignyana	6.2	2.68	3.35	4.02	4.69	5.03	3.50	4.38	4.81
Sepietta oweniana	NA	2.20	2.75	3.30	3.85	4.13			
Serranus cabrilla	11.7	9.32	**11.65**	13.98	16.31	17.48	**14.12**	17.65	19.42
Serranus hepatus	8.5	**8.76**	10.95	13.14	15.33	16.43			
Spicara flexuosa	10.1	**13.44**	16.80	20.16	23.52	25.20			
Spicara maena	12.1	**12.97**	16.22	19.46	22.70	24.33	**15.42**	19.28	21.20
Spicara smaris	NA	12.43	15.54	18.65	21.76	23.31	17.12	21.40	23.54
Sprattus sprattus	NA	13.12	16.40	19.68	22.96	24.60			
Squilla mantis	12	7.36	9.20	11.04	**12.88**	13.80			
Trachinus draco	12	**13.32**	16.65	19.98	23.31	24.98	**18.12**	22.65	24.92
Trachurus spp	18.8	12.75	15.94	**19.12**	22.31	23.90	14.98	**18.73**	20.60
Triglidae	18-25						14.04	17.55	19.31
Trisopterus minutus	12.6	10.01	12.52	**15.02**	17.52	18.78	**12.89**	16.12	17.73
Upeneus moluccensis	11.7	**12.20**	15.25	18.30	21.35	22.87	**16.69**	20.86	22.95
Upeneus spp	NA	10.43	13.03	15.64	18.25	19.55	14.70	18.38	20.21

gear selectivity and reduce seafloor impacts are urgently needed to return this fishery to sustainability. Techniques devised elsewhere (e.g., the North Atlantic) may be of limited value in improving selectivity in multi-species Mediterranean fisheries: here, studies of selection devices should be conducted to find approaches that reduce bycatch and discards for each fishery and target species, thus restoring stocks and fishery sustainability.

In brief, the main results of the present review can be summarized as follows.

- For the same *MS*, the *SM* codend is more selective than the *DM* codend for 60% of the species tested.
- Within the current regulatory framework (Resolution GFCM/31/2007/3), the *SM40* codend is slightly more selective than the *DM50* codend.
- The legal *MSs* and configurations (*SM40* and *DM50*) do not seem to ensure the exclusive catch of mature specimens of several species, since 68% and 64% of the species investigated for the *DM50* and the *SM40*, respectively, were under the *LFM*.
- The legal *MSs* and configurations appear to be unable to protect undersized specimens of several species, since the *L50* of 78% of the species investigated was under the *MCRS*.
- The *MCRS* set for some species should be revised, since it is under the *LFM*, hence ecologically inadequate, for 59% of the species investigated.

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Supplementary data

The following supplementary material is available online for the article:
Table S1. Review of Length at first maturity of Mediterranean marine species.
Table S2. Review of bottom trawl selectivity studies in the Mediterranean Sea.
References of the Length at first maturity for Mediterranean marine species and of the selectivity studies.