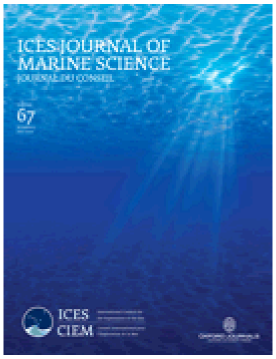

Escape, discard and landing probability in multispecies Mediterranean bottom trawl fishery

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Keyword:	selection model, bycatch, trawl codend, diamond mesh, square mesh, escapees, landings, discard mitigation, Mediterranean

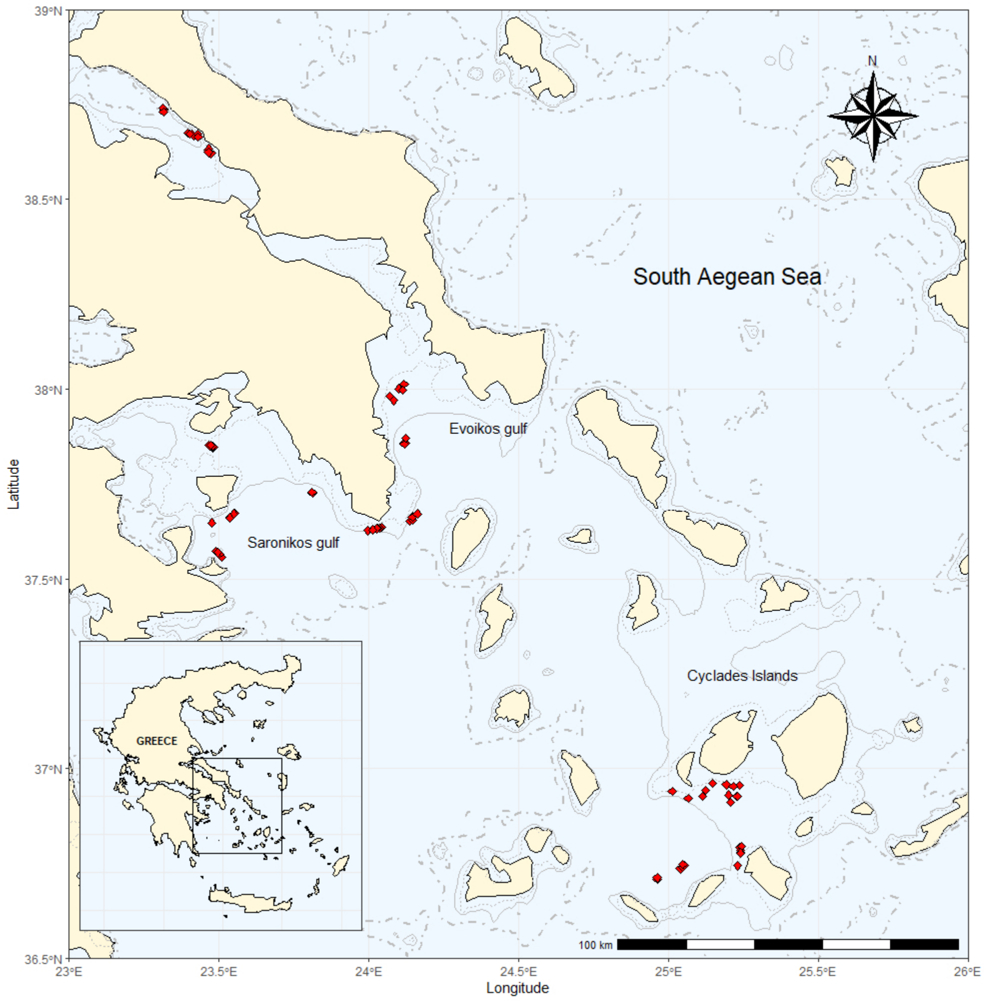
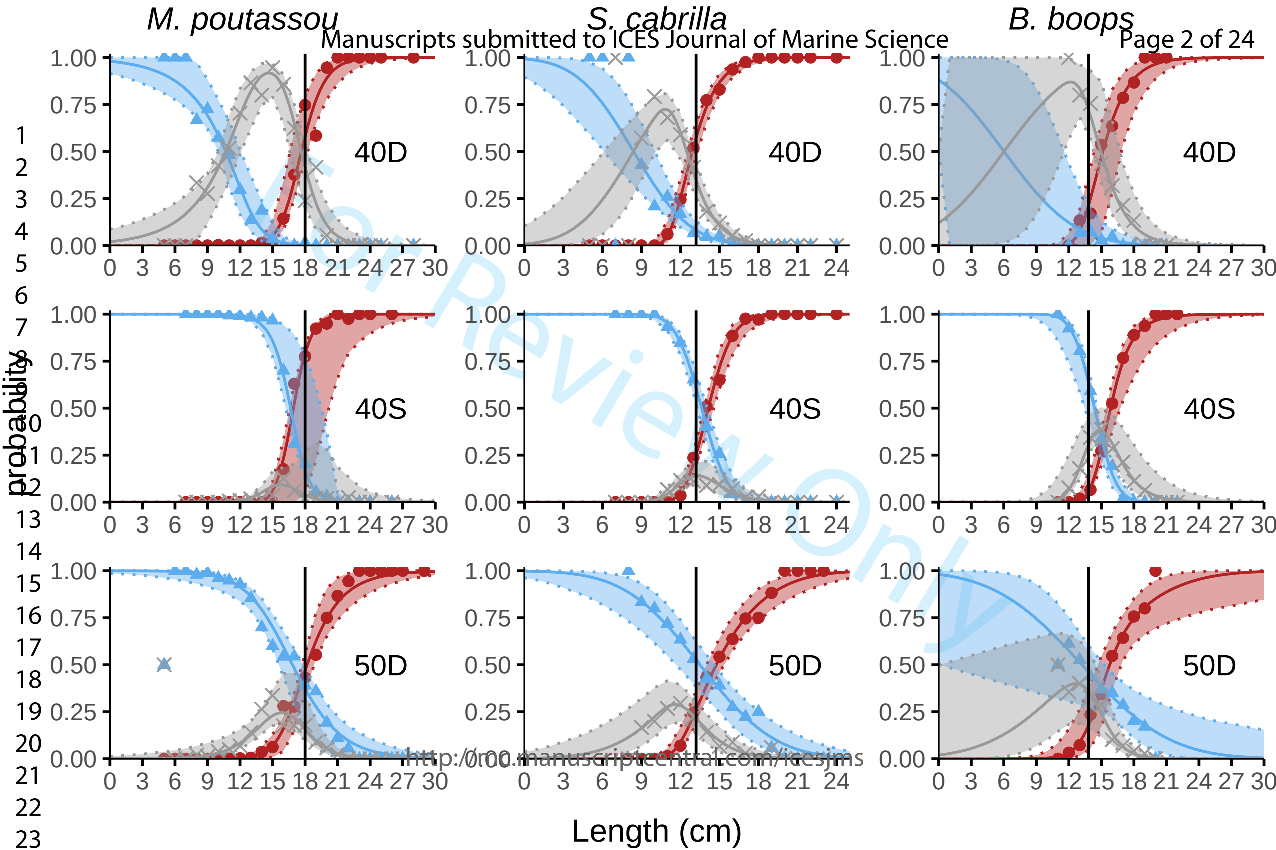
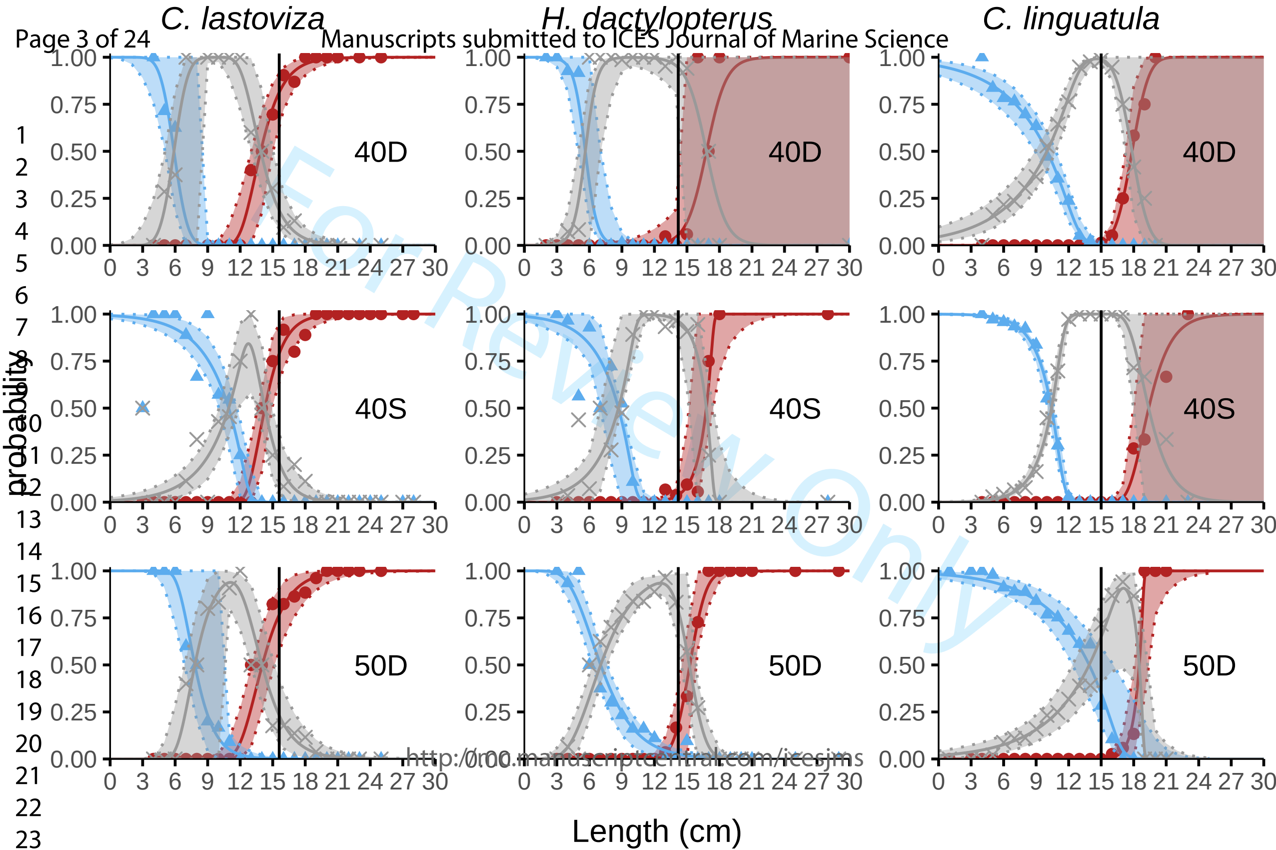


Figure 1. Map of the study area, indicating the hauls (red diamonds) of the experimental fishing; isobaths 50, 100, 300 m: dots, continuous, dashed lines, respectively.

170x170mm (149 x 149 DPI)


M. poutassou
S. cabrilla
B. boops
40D
40S
50D
probability
Length (cm)
0.00
0.25
0.50
0.75
1.00
0 3 6 9 12 15 18 21 24 27 30
0 3 6 9 12 15 18 21 24


C. lastoviza
H. dactylopterus
C. linguatula
40D
40S
50D
probability
Length (cm)
0.00
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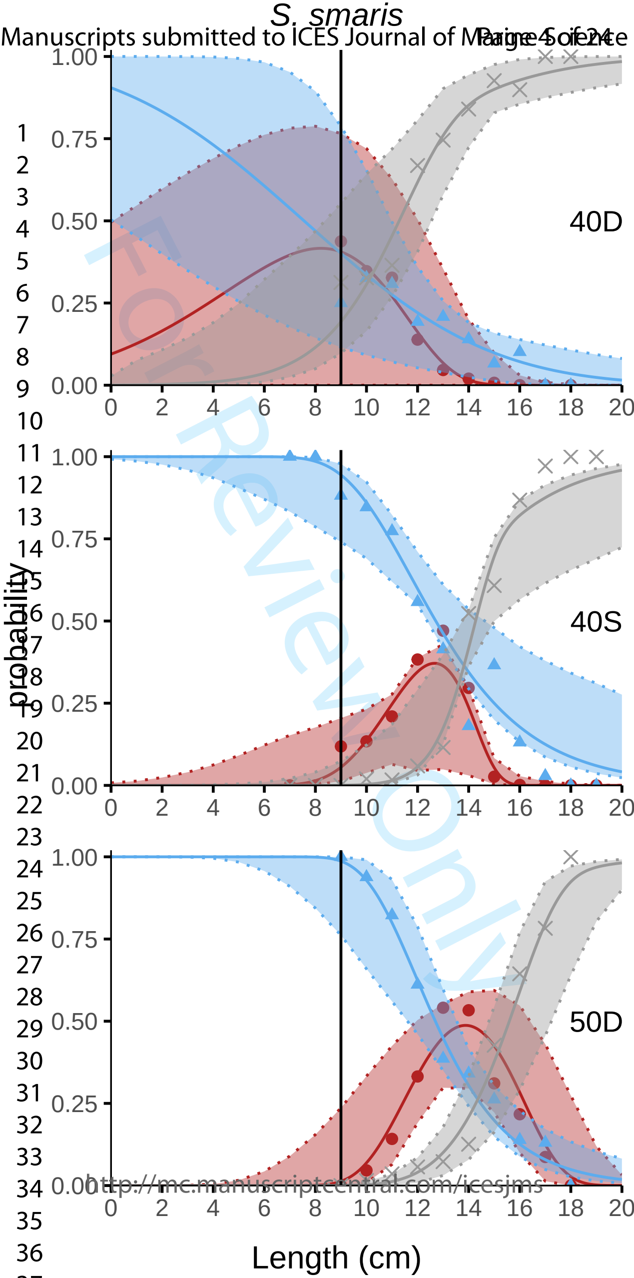
S. smaris
probability
40D
40S
50D
0.00
0.25
0.50
0.75
1.00
0
2
4
6
8
10
12
14
16
18
20
Length (cm)

ICESJMS-2020-714 (EA)

Escape, discard, and landing probability in multispecies Mediterranean bottom-trawl fishery

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Commercial bycatch species and their exploitation pattern in the Mediterranean trawl fishery are little studied. The present work examines the overall size-selection pattern, both regarding the trawl in the sea and the fisher onboard the vessel, for seven commercial bycatch species using different codends. The applied selection model predicted the escape, discard, and landing probability for each species simultaneously, a useful method for providing information important for fisheries management under the ecosystem approach. Among the studied codends, the 40-mm diamond mesh codend, still in use in non-EU Mediterranean fleets, was found unsuitable for the stocks in all cases. The 40-mm square mesh codend (40S) was found appropriate for blue whiting (*Micromesistius poutassou*), comber (*Serranus cabrilla*), and bogue (*Boops boops*) sustainability. The 50-mm diamond mesh codend (50D) was more suitable than the square mesh codend only for the spotted flounder (*Citharus linguatula*, Linnaeus, 1758). Both the 40S and the 50D codends were appropriate for picarel (*Spicara smaris*), whereas none ensured sustainable exploitation for the blackbelly rosefish (*Helicolenus actylopterus*, Delaroche, 1809), and the streaked gurnard (*Chelidonichthys lastoviza*). The results are discussed in relation to juvenile protection, discard mitigation, and fisher selection behaviour, important factors for the sustainability of stocks and fisheries in the Common Fishery Policy for the Mediterranean Sea.

Keywords: bycatch, diamond mesh, discard mitigation, escapees, landings, Mediterranean, selection model, square mesh, trawl codend**.**

Introduction

The management of the Mediterranean bottom-trawl fishery has proved challenging due to its multispecies nature. This challenge is related to the relatively low number of primary target species of high commercial value, the great number of bycatch species that are generally of low and/or occasional commercial importance, and a significant amount of discarded organisms. Many definitions have been used for the term "*bycatch"* (Kelleher, 2005), but in many instances, as in this work, it is considered to be "the incidental capture of non-target organisms" (Tsagarakis *et al*., 2014). Commercial bycatch can play an important role in the

Mediterranean trawl fishery depending on their economic value and/or abundance and can be an essential supplementary source of income for fishers (Tsagarakis *et al.*, 2017). Bycatch also plays an important role in biodiversity and ecosystem sustainability. As a result, changes in trawl selectivity that affect the target and non-target species may lead to various direct or indirect effects on the ecosystem (Coll *et al.*, 2008).

The establishment of the use of the 40-mm square or the 50-mm diamond mesh for the Mediterranean trawl codend (EC Regulation 1967/2006; REC.CM-GFCM/33/2009/2) has not been a sufficient measure to considerably improve the selectivity of this gear and eliminate discards, undersized, and/or unwanted catch (Brčić *et al.*, 2015, not in reference list 2018; Damalas *et al.*, 2018; Mytilineou *et al.*, 2018). On the other hand, despite the multispecies character of the Mediterranean trawl fishery, no minimum conservation reference size (MCRS) has been established for commercial bycatch species, but only for the most commercially important ones (EC Regulation 1967/2006). Moreover, most commercial bycatch species remain unregulated, are not subject to the landing obligation (Regulation (EU) No 1380/2013), and are not assessed by the General Fisheries Commission for the Mediterranean (GFCM). Therefore, information relevant to the exploitation pattern of these species is particularly necessary in the context of the ecosystem approach to fisheries management.

In most cases, fishing gear selectivity and discards have been examined separately. Trawl selection parameters for some commercial bycatch species in the Mediterranean, such as blue whiting (*Micromesistius poutassou*, Risso, 1810), bogue (*Boops boops*, Linnaeus, 1758), and blotched picarel (*Spicara maena*), have been published in the past (Petrakis and Stergiou, 1997; Ordines *et al.*, 2006; Sardà *et al.*, 2006; Sala and Lucchetti, 2010; Tokaç *et al.*, 2010; Özbilgin *et al.*, 2012; Eryaşar *et al.*, 2014). A few studies on the discards of commercial bycatch species and the length at which 50% of them are discarded, based on data from onboard observers, have also been conducted (Machias *et al.*, 2004; Tsagarakis *et al.*, 2017; Damalas *et al.*, 2018).

Mytilineou *et al.* (2018) introduced a model which describes the overall size-selection process of fish entering the trawl codend by combining the two independent but sequential selection processes, that of the gear and that of the fisher. This model, which quantifies the size-related probabilities of escapees, discards, and landings, was applied in the present work to model the overall size selection of several commercial bycatch species that are of lower priority for the Mediterranean bottom-trawl fishery. The aim was to investigate (i) whether the model proposed by Mytilineou *et al.* (2018) can also be applied to more species than the three tested by these researchers and (ii) if so, to gather important information for fisheries management related to juvenile protection, first maturity, discards, and fishers' selection behaviour for landings. The study included seven commercial bycatch non-regulated species: blue whiting, comber (*Serranus cabrilla*, Linnaeus, 1758), bogue, streaked gurnard (*Chelidonichthys lastoviza*, Bonnaterre, 1788), blackbelly rosefish (*Helicolenus actylopterus*), spotted flounder *Citharus linguatula*), and the picarel (*Spicara smaris*, Linnaeus, 1758); species of different economic value, different body shape characteristics, and without MCRS. Differences among three codends, made by diamond or square meshes, were also examined.

Material and methods

Data collection

Data were collected during a 23-day experimental fishing survey (May–June 2015) carried out in the fishing grounds of the South Aegean Sea (E. Mediterranean) (Figure 1). A total of 84 hauls were conducted with three different codends (28 hauls per codend). Each haul lasted 1 h, and the vessel speed was 2.8 knots. Some hauls were excluded due to the very low number of individuals for the studied species or to damaged net or poor net performance, which was checked with SCANMAR system. Fishing depth ranged from 50 to 310 m, a good representation of the main depth range for the commercial trawl fishery. A chartered trawler, equipped with a commercial gear set-up, was used. The codends used in the experimental fishing were: (i) a codend of 40-mm nominal size square meshes (40S) (actual mesh size: 43.2 ± 0.6 mm), (ii) a codend of 50-mm nominal size diamond meshes (50D) (actual mesh size: 51.1 ± 0.7 mm), and (iii) a codend of 40-mm nominal size diamond meshes (40D) (actual mesh size: 43.2 ± 0.6 mm). The 40S and 50D codends have been established in the commercial Mediterranean trawl fishery according to the Council Regulation 1967/2006 and the GFCM Recommendation REC.CM-GFCM/33/2009/2. The 40D codend, although prohibited for EU Mediterranean countries, was examined in this study for comparison purposes, since similar or smaller meshes are still in use in other Mediterranean trawl fleets. The average mesh size (± s.e.) for each codend was based on the measurement of 100 meshes per codend using an ICES mesh gauge with 4-kg tension while the net was wet. The three knotless codends (5.6-m in length in all cases) were made by single twine multifilament nylon (PA) of 2.8-mm thickness. The number of meshes in codend circumference was 400, 200, and 340 meshes for the 40D, 40S, and 50D, respectively, in order to achieve almost the same circumferential length at sea (~4.3 m) (for details, see Supplementary material Table S1, Figure S1, and Sala *et al*., 2015).

Data for seven bycatch commercial and/or occasionally commercial species, *M. poutassou, S. cabrilla, B. boops, C. lastoviza, H. dactylopterus*, *C. linguatula*, and *S. smaris,* were collected for the purposes of this work. There is no MCRS for these species. The only related but very old legislation for the Greek fishery is a National Royal Decree (R.D. 916/1966) with minimum landing size (MLS) for *B. boops* at 10 cm and MLS for non-regulated species at 8 cm, which are generally very small and were established in a period when smaller mesh sizes were in use for the trawl codend. Since no MCRS currently exists for the above-mentioned species, the selection parameters in this study were compared with the size at first maturity of each species, information published in the literature. For a species, selection parameters similar to or above this size indicate that the species has the opportunity to reproduce at least once and, therefore, the gear used supports the species sustainability.

The three-fraction sampling design into escapees, discards, and landings was also used in this work as described in Mytilineou *et al*. (2018). For the escapees, the cover-codend method (Wileman *et al*., 1996) was used to collect the trawl codend size-selectivity data. The experimental design for the cover-codend method was similar to that presented by Sala *et al.* (2015) with a 20-mm diamond mesh size net for the cover. For the discards and landings, the vessel crew was asked to sort the codend catch as they normally do under normal commercial fishing conditions. During this process, the entire catch was emptied onto the vessel deck and the commercially important portion was sorted into baskets by the crew. Then, the remaining unwanted portion, which during commercial fishing is discarded, was placed by the scientists on a table so that it could be sorted by species, counted, weighed, and measured. For each studied species in each haul, measurements were taken from all individuals of each fraction (escapees, discards, landings). However, in case of numerous individuals in any of the three fractions, a random subsample was used. In this case, 200 measurements were recorded; a sufficient number for a 5% uncertainty according to Herrmann *et al*. (2016). In some cases, a smaller number of measurements than expected was obtained due to damaged fish or bad weather conditions.

The overall size-selection model

The model which describes the overall size selection (during the fishing operation and onboard the vessel) used in the present work was first presented by Mytilineou *et al*. (2018).

As it is mentioned by these researchers, a fish of length l entering the codend during the towing of the gear in the sea will end up as an escapee, discard, or landing following a multinomial distribution with one of three "fates" (probabilities): (i) escape through the meshes of the codend in the sea, described by the probability $p_{esc}(l,\boldsymbol{v}_{gear})$; (ii) discarded by the fisher, given that it had been retained in the trawl codend, described by the probability $p_{disc}(l, \boldsymbol{v}_{gear}, \boldsymbol{v}_{fisher})$; and (iii) landed in the harbour, provided that it had been retained in the trawl codend, described by the probability $p_{land}(l, \boldsymbol{v}_{gear}, \boldsymbol{v}_{fisher})$. The vectors $\boldsymbol{v}_{gear}$ and $\boldsymbol{v}_{fisher}$ represent the parameters of two independent, but sequential, selection processes: (i) the gear size selection with retention probability $r_{gear}(l,\boldsymbol{v}_{gear})$ and (ii) the fisher size selection with retention probability $r_{fisher}(l,\boldsymbol{v}_{fisher})$. Based on this, the three probabilities p_{esc}, p_{disc}, and p_{land} can be described as follows:

$$\begin{aligned} p_{esc}(l,\boldsymbol{v}_{\boldsymbol{gear}}) &= 1.0 - r_{gear}(l,\boldsymbol{v}_{\boldsymbol{gear}}) \\ p_{disc}(l,\boldsymbol{v}_{\boldsymbol{gear}}, \boldsymbol{v}_{\boldsymbol{fisher}}) &= [1.0 - r_{fisher}(l,\boldsymbol{v}_{\boldsymbol{fisher}})] \times r_{gear}(l,\boldsymbol{v}_{\boldsymbol{gear}}) \\ p_{land}(l,\boldsymbol{v}_{\boldsymbol{gear}},\boldsymbol{v}_{\boldsymbol{fisher}}) &= r_{gear}(l,\boldsymbol{v}_{\boldsymbol{gear}}) \times r_{fisher}(l,\boldsymbol{v}_{\boldsymbol{fisher}}) \end{aligned} \qquad (1)$$

Analysis of data and selection parameters estimation

In the present work, the Logit, Probit, Gompertz, and Richard selection models (Wileman *et al.*, 1996) were considered to describe the gear and fisher retention probabilities and, based on these, the escape, discard, and landing probabilities. The selection parameters of these models are: *L50* (the length at which 50% of fish are retained), *SR* (the selection range = *L75* – *L25*) and the additional parameter for Richard model 1/δ (describing the amount of asymmetry of the curve). The above parameters were denoted for the gear or the fisher ($L50_{gear}$, SR_{gear}, and $L50_{fisher}$, SR_{fisher}). Besides these selection parameters, based on the curve for the landing probability $p_{land}(l, \boldsymbol{v}_{gear}, \boldsymbol{v}_{fisher})$, the parameters $L50_{land}$ and SR_{land} were also estimated, denoting the length of a fish entering the trawl codend with 50% probability to be landed. This estimation followed the numerical technique described in Sistiaga *et al.* (2010), as applied in Mytilineou *et al.* (2018). In general, p_{esc} and p_{land} are described by S-curves, and p_{disc} by a bell-shaped curve (Mytilineou *et al.*, 2018). However, if the fisher selection pattern changes, selecting the smaller individuals as landings and the bigger as discards, then p_{disc} is expected to be described by an S-curve and p_{land} by a bell-shaped curve. In this case, the $L50_{disc}$ and SR_{disc} can be estimated based on the S-curve.

The estimation of the selection parameters of the models was based, as in Mytilineou *et al.* (2018), on the maximum log-likelihood function taking into account the subsampling ratios (see the function in the Supplementary material). The use of the four selection models for each selection process in the formulas (1) resulted in 16 potential overall models. The evaluation of each overall model was based principally on the *p*-value, which expresses the likelihood of obtaining at least as large a deviation between the experimental data and the applied model by coincidence (should be >0.05; Wileman *et al.*, 1996). If the *p*-value <0.05, the residuals were inspected to determine if this was due to overdispersion. A secondary criterion was related to the model deviance (D), which should be close to the number of degrees of freedom (d.f.). Then, the lowest value of AIC criterion (Akaike, 1974) indicated the best model.

The estimation of the mean selection curves is generally based on the individual haul selectivity (Fryer, 1991). However, Millar (1993) proposed to estimate a single "average" curve in the case of fisheries issues by pooling the data for all hauls. In this study, data were pooled to estimate the average size selection over all the available hauls, and the double bootstrapping method was used (Efron, 1982) to incorporate the within- and between-haul variation in the estimates (Millar, 1993). The estimation of the "*Efron percentile 95% confidence limits*" (95% CI) of each selectivity curve (Efron, 1982) was based on 1000 bootstrap repetitions. The method, extensively applied in several works (e.g. Sistiaga *et al.*, 2010; Herrmann *et al.*, 2012, 2013, 2019; Sala *et al.*, 2015; Mytilineou *et al.*, 2018; Larsen *et al.*, 2019), was implemented by using the computer software SELNET (Herrmann *et al.*, 2012, 2013).

Comparison of selection curves and parameters between gears

In the present work, the analysis of data was implemented by species and codend mesh. Overlap of the 95% CI of the gear, fisher, and landings selection parameters was used to compare the parameters of the three codends (as proposed by Frandsen *et al.*, 2010). Moreover, the length-dependent difference $\Delta p_{esc}(l)$ in the escape $p_{esc}(l)$ size-dependent probability between the three codends was estimated in each length class *l* as follows:

$$\begin{gathered}\Delta p_{esc}(l) = p_{esc\_50D}(l) - p_{esc\_40S}(l)\\ \Delta p_{esc}(l) = p_{esc\_50D}(l) - p_{esc_{40D}}(l)\\ \Delta p_{esc}(l) = p_{esc\_40D}(l) - p_{esc\_40S}(l)\end{gathered}\qquad(2)$$

Similarly, the differences $\Delta p_{disc}(l)$ in the discard probability $p_{disc}(l)$ and $\Delta p_{land}(l)$ in the landing probability $p_{land}(l)$ among the three codends were also estimated in each length class *l*. The Efron 95% percentile confidence limits for *Δ(l)* were obtained based on the bootstrap results of each probability $p(l)$. Since these probabilities are estimated independently, a new bootstrap can be generated for each *Δ(l)* (Moore *et al.*, 2003). If the 95% CI of the difference in a length class include the 0-axis, then the difference is not statistically significant for that length class. This methodology has been described and applied by Larsen *et al.* (2019) for probabilities and by Mytilineou *et al.* (2020) for populations. The plots of the differences $\Delta p_{esc}(l)$, $\Delta p_{disc}(l)$, and $\Delta p_{land}(l)$ are shown in the Supplementary material (Figures S2–S8).

Results

Experimental fishing data

Table 1 presents the total number of individuals and their percentage to the total catch of *M. poutassou, S. cabrilla, B. boops, C. lastoviza, H. dactylopterus, C. linguatula*, and *S. smaris* measured in the three fractions: the escapees (in cover), the discards, and the landings (in codend). This information by haul and the range of total lengths measured for each codend are shown for each species in Tables S2–S8 in the Supplementary material. The total catch of each haul is also presented in Supplementary Table S9. *C. linguatula* and *S. cabrilla* were fished in many hauls (19 and 14, respectively). The rest of the species were caught in fewer hauls (5–9) and, in some cases, in very low numbers (e.g. *H. dactylopterus,* Table 1) because the sampling design was based on hauls of the commercial trawl fishery targeting mainly hake and mullets, accompanied by other species mainly as bycatch.

Modelling the escape, discard, and landing size-dependent probability by species and codend type

In general**,** the model applied in this work fitted the data adequately for the three codends (40D, 40S, and 50D) and the three fractions (escape, discards, landings). However, the low number or absence of individuals from some length classes produced wide 95% CI in the escape, discard, or landing probability curves in a few cases (Figures 2, 3, and 4). For *S. smaris,* the fitted model differed from that of the other species. This was because the smallest of the caught individuals are mainly selected by the fishers as landings, whereas the largest ones are discarded. As a result, the landing probability was represented by a bell-shaped curve, while the discard probability was fitted as an S-curve (Figure 4). Consequently, the fisher-related SR was negative, reflecting the fisher's special behaviour (Table 4). In the case of the 40S and the 50D codend for this species, the estimated *p*-value was low, although the model fitted the data well. This was attributed to the high dispersion in the data. In fact, in some cases, small sizes were also discarded or large ones sorted as landings because of (i) the low number of specimens in some of the hauls of the experimental fishing, (ii) the composition and abundance of other species in the catch affecting fisher selection, (iii) the sensitivity of small sized picarels, which are easily damaged during the onboard process, and (iv) the fact that picarel is not a target species in the trawl fishery.

M. poutassou

$L50_{gear}$ of *M. poutassou* was significantly lower for the 40D than for the other two codends. Similar $L50_{gear}$with overlap of their 95% CI was found for the 40S and the 50D (Table 2). Only $L50_{gear}$ for 40S included the length at first maturity ($L50_{mat}$) of the species in its 95% CI (Table 2, Figure 2). The escape probability was significantly higher for the 40S than the 40D and 50D for small lengths (Figure 2, Supplmentary Figure S2). Higher escape probability was found for the 50D than the 40S for large sizes (Supplementary Figure S2), related to the significantly higher selection range of the 50D (Table 2). The discard probability for 40D, indicating that a large amount of *M. poutassou* entering the 40D gear will be discarded (Figure 2), presented statistically significant differences compared to those of the 40S and 50D (Supplmentary Figure S2). Significantly higher discard likelihood was also found for the 50D than 40S for the sizes 12–16 cm TL (Supplementary Figure S2). Finally, $L50_{land}$ (close to $L50_{mat}$) and SR_{land} of *M. poutassou* were very similar among the three codends with an overlap in their 95% CI (Table 2). Fisher landing selection showed no significant differences among the three codends (Figure 2, Supplementary Figure S2).

S. cabrilla

$L50_{gear}$of *S. cabrilla* was significantly lower for the 40D, compared to the other two codends; for 40S and 50D, similar to the $L50_{mat}$ of the species (Table 2, Figure 2). The selection range was significantly lower for the 40S (Table 2), indicating a higher escape probability with diamond codends for large individuals, particularly with 50D. Significantly higher escape probability was found for the 40S and 50D compared to the 40D for small sizes, followed by statistically significant differences in discard probability between the 40D and the other two codends (Figure 2, Supplementary Figure S3). The escape likelihood differed also significantly between the 50D and the 40S (lower at small sizes and higher at large ones for 50D; Supplementary Figure S3). In contrast, discard probability was higher in small sizes for 50D than 40S (Supplementary Figure S3). $L50_{land}$ of *S. cabrilla* was very similar between the 40S and 50D codends with an overlap in their 95% CI, which differed significantly from that of 40D (Table 2). Significantly higher landing probability was detected for the 40D than the 40S and 50D at small sizes and for the 40S than the 50D at larger ones (Figure 2, Supplementary Figure S3).

B. boops

$L50_{gear}$of *B. boops* was lower for the 40D than for the other two codends. Close values for $L50_{gear}$were obvious for the 40S and 50D; similar to $L50_{mat}$ of the species (Table 2, Figure 2). However, escape probability in the 40S was significantly higher for small sizes and lower for large sizes than in 50D; the opposite for discard probability (Supplementary Figure S4). The selection range was much higher for the 40D and particularly for 50D than for 40S

(Table 2), explaining the higher escape probability for large individuals with 50D. Significantly higher escape probabilities were detected for the 40S and 50D than the 40D in small sizes; the opposite for their discard probability (Figure 2, Supplementary Figure S4). $L50_{land}$ (higher than $L50_{mat}$ in all cases) and SR_{land} of *B. boops* were very similar among the three codends with an overlap in their 95% CI (Table 2). Fisher landing selection seemed almost similar in all cases (Figure 2, Supplementary Figure S4).

C. lastoviza

$L50_{gear}$ of *C. lastoviza* was significantly lower for the 40D than 40S (Table 3); that of 50D was between the values of the other two codends displaying overlap among their 95% CI (Table 4). In all cases, $L50_{gear}$was lower than $L50_{mat}$ of the species (Table 3, Figure 3). The selection range was lower for the 40D and 50D and higher for 40S, but with considerable overlap in their 95% CI (Table 3). Statistically significant higher escape probability was detected for the 40S than 40D for small lengths, followed by a higher discard probability for 40D in the same sizes (Figure 3, Supplementary Figure S5). No important differences were detected between the 50D and 40D and between the 50D and 40S for both the escape and discard probability (Figure 3, Supplementary Figure S5). The discard probability demonstrated that a large amount of *C. lastoviza* entering the gear will be discarded in all cases (Figure 3). The landing probability of the species and the related parameters $L50_{land}$ and SR_{land} were very similar among the three codends, with an overlap in their 95% CI (Table 3, Supplementary Figure S5). In all cases, $L50_{land}$ was lower than the $L50_{mat}$ of the species (Table 3, Figure 3).

H. dactylopterus

$L50_{gear}$of *H. dactylopterus* was considerably lower for the 40D than the 40S codend; that of the 50D was between the values of the other two codends presenting overlap with their 95% CI (Table 3). In all cases, $L50_{gear}$ was significantly lower than the $L50_{mat}$ of the species (Table 3, Figure 3). The predicted selection range was lower for 40D, although significantly different only compared to 50D (Table 3). Statistically significant lower escape and higher discard probabilities were detected for the 40D than the 40S and 50D and for the 40S than the 50D for small lengths, but with negligible values (Figure 3, Supplementary Figure S6). The discard probability showed high values for all codends (Figure 3). The landing probability of *H. dactylopterus* and the parameters $L50_{land}$ and SR_{land} were similar among the three codends, with an important overlap in their 95% CI (Table 3, Supplementary Figure S6). $L50_{land}$ was always larger than the $L50_{mat}$ of the species (Table 3, Figure 3).

C. linguatula

Significantly higher $L50_{gear}$ was found for *C. linguatula* using the 50D than the other two codends, which was also close to the $L50_{mat}$ of the species (Table 3, Figure 3). The overlap of the 95% CI of $L50_{gear}$ was obvious between the 40D and 40S (Table 3). However, significantly higher escape probability was detected for the 40S than the 40D and 50D for lengths ≤9 cm, but significantly lower for larger ones; the opposite for their discard probability (Figure 3, Supplementary Figure S7). This was related to the significantly higher selection range for both diamond codends, indicating a higher escape probability for these codends than the 40S in sizes ≥10 cm TL (Table 3). Higher escape probability was found for the 50D compared to the 40D for lengths ≤19 cm TL, accompanied by a higher discard probability for the 40D in the same sizes (Figure 3, Supplementary Figure S7). The discard probability indicated that a large amount of *C. linguatula* entering the tested gears will be discarded in all cases (Figure 3). The parameters $L50_{land}$ and SR_{land} of *C. linguatula* showed no significant differences among the three codends, a fact that may be related to the wide 95% CI of 40D and 40S (Table 3). $L50_{land}$ was always larger than the $L50_{mat}$ of the species (Table 3, Figure 3).

S. smaris

The escape probability of *S. smaris* differed between the 40D and the other two codends, with significantly lower $L50_{gear}$ for 40D. However, this was close to the length at first maturity of the species, while that of 40S and 50D was significantly higher (Table 4, Figure 4). $L50_{gear}$ for the 40S and 50D were similar, and their 95% CI showed overlap (Table 4). The selection range, although higher for the 40D, showed overlap of 95% CI among the three codends (Table 4). The escape probability for the 40D was significantly lower and the discard probability significantly higher than that of the 40S or 50D for lengths <16 cm TL (Figure 4, Supplementary Figure S8). No differences were found between the 50D and the 40S for the escape probability, whereas the difference between their discard probability was negligible (Supplementary Figure S8). The landing probability of *S. smaris* showed higher values for the 40D than for the other two codends (Figure 4, Table 4). However, no statistically significant difference was identified among the three codends (except between the 50D and the other two gears for the sizes 14–17 cm), but this may be related to the wide 95% CI for the landing probability of 40D (Figure 4, Supplementary Figure S8).

Discussion

The overall size selection of the trawl codend was studied in this work for seven commercial bycatch species, *M. poutassou, S. cabrilla, B. boops, T. lastoviza, H. dactylopterus*, *C. linguatula*, and *S. smaris*, based on the model described by Mytilineou *et al*. (2018). The model, which simultaneously predicts the escape, discard, and landing probability for a species entering the trawl codend as two consecutive selection processes, first by the gear in the sea and then by the fisher onboard the fishing vessel, fitted the data well in all cases. This demonstrates that the model can also be applied to species other than those studied by Mytilineou *et al*. (2018). It should be noted, however, that, in case of poor data (low number of hauls or low number of individuals), 95% CI may be wide.

In general, from the catch retained by the gear, fishers select the large individuals and discard the smaller ones, processes described by S-curves for the escape and the landing probability, and by a bell-shaped curve for the discard probability. However, in the case of *S. smaris,* because of the consumers' preference for small picarels, fishers follow the opposite pattern, described by an S-curve for the discard probability and a bell-shaped curve for the landing probability. Thus, the model used can also describe different selection patterns.

Commercial bycatch species do not receive high attention in research and management, since they do not constitute main targets in fisheries. However, they suffer all the collateral effects from fisheries and, therefore, need to be subject to sustainable exploitation. It should be noted here that the majority of these species show low or negligible survival rates when discarded (Tsagarakis *et al*., 2018). The species examined in this work are not of high economic importance in the Mediterranean fishery, as they represent a low percentage of the total annual catches in the area (2.0%; FAO Fisheries Statistics 2017) and their commercial price is generally low. However, their role is not negligible, since they can contribute to the fishers' individual income (Tsagarakis *et al*., 2017) and they can also be considered as a low-cost fish protein source for the public. Moreover, they play an important role in biodiversity and ecosystem health, because of their role in the foodweb where they constitute prey of the top predators (Stergiou and Karpouzi, 2002). Therefore, a decrease in their biomass may produce trophic cascades (Coll *et al*., 2008). This work provides information on their exploitation by the bottom-trawl fishery related to their juvenile protection, and fisher selection behaviour for discards and landings, information indispensable in fisheries management.

For all species examined, 40D had a very low gear selectivity resulting in a high retention probability of juveniles, as also noted by many researchers (Petrakis and Stergiou, 1997; Ordines *et al*., 2006; Sala and Lucchetti, 2010; Tokaç *et al*., 2010; Mytilineou *et al*., 2018). As a result, it is accompanied by a high discard probability and large amounts of discards (Mytilineou *et al*., 2018), since generally small sized individuals are prohibited to be landed or are not of interest for the market. Even when small individuals are preferred as landings, such as in *S. cabrilla*, the use of 40D allows the fisher to act unsustainably for the stocks. Similar consideration has been mentioned by Mytilineou *et al*. (2018) for hake. The 40D codend can be considered detrimental for the stocks; for this reason, its use is not currently allowed by the EC Regulation 1967/2006 and REC.CM-GFCM/33/2009/2 for Mediterranean waters. However, smaller (25 mm; Ragheb *et al*., 2019) or a little larger (44 mm; Ilkyaz *et al*., 2017) diamond meshes are still in use by fishing fleets in non-EU Mediterranean countries.

For *M. poutassou,* only the $L50_{gear}$ for the 40S was comparable to the length at first maturity of the species. For *S. cabrilla* and *B. boops,* their length at first maturity was similar to the values of $L50_{gear}$ for both the 40S and 50D codends. For all three species, 50D presented a higher SR_{gear} resulting in (i) the retention of smaller individuals that will be discarded and (ii) the escapement of larger than the $L50_{mat}$ ones, which are commercially important. On the other hand, for both codends, $L50_{land}$ was quite similar or higher than $L50_{mat}$ in all cases, showing that the fisher selection pattern was constant and in accordance with the sustainability of the stock. It could, therefore, be suggested that for *M. poutassou, S. cabrilla*, and *B. boops*, the 40S is more adequate compared to the 50D in terms of juvenile protection, stock sustainability, discard mitigation, and because of less economic losses.

C. lastoviza and *H. dactylopterus* presented the highest $L50_{gear}$ value for the 40S, but in all cases this parameter was significantly lower than the length at first maturity of the species. Fisher selection for landings, similar for all codends, was lower than the $L50_{mat}$ of *C. lastoviza*; it was higher for *H. dactylopterus*. Discard probability was always high for both species. Therefore, none of the three codends was found suitable for *C. lastoviza* and *H. dactylopterus* in terms of juvenile protection and discard quantities. Gear selectivity needs considerable improvement. This was probably related to the body features of these species, characterized by large pectoral fins used during movement in *C. lastoviza* and the presence of many spines in *H. dactylopterus,* which do not permit their escapement through the net. They also have a benthic and relatively inactive behaviour during fishing in the net (Mytilineou, unpublished data) that does not support their escape likelihood.

C. linguatula presented a significantly larger $L50_{gear}$ for the 50D, compared with the other codends, including the $L50_{mat}$ of the species in its 95% CI. This let us suggest that this codend could support the sustainability of this species. It is well known that diamond meshes are more selective than square meshes for flatfish, such as *C. linguatula* (Sala *et al*., 2008; Özbilgin *et al*., 2012; Mytilineou *et al*., 2018). The discard probability for the 50D was significantly lower compared to the other two codends, but still high, indicating that a large part of the total amount of *C. linguatula* entering the trawl with the 50D codend will be discarded. This was mainly related to the fisher selection pattern; the latter resulting in the selection of larger individuals than the length at first maturity of the species in all cases. Based on the predictions of the model, although 50D is good enough for juvenile protection and stocks sustainability, a change in fisher behaviour or market demand seems necessary for the mitigation of the discards. In the opposite case, improvement of the gear selectivity is still required.

Similar $L50_{gear}$ for the 40S and 50D was found for *S. smaris,* significantly higher than the length at first maturity of the species. $L50_{gear}$ for the 40D, although lower, it included the length at first maturity of the species between its 95% CI. However, the discard probability of 40D was significantly higher for this codend compared to the other two. On the other hand, although 40D showed a higher landing probability in smaller sizes, which could indicate some economic losses for the other two codends, these are not expected to be important, since the differences were not statistically significant. *S. smaris* is not a target species for the trawl fishery and is of relatively low economic value. Important economic losses for the change from 40D to 40S have been reported by Ordines *et al.* (2006). However, these researchers have found a much higher value for $L50_{gear}$ than our results (Table 5), which probably resulted in more important catch losses than in our case. Therefore, the 40S and 50D codends seem more adequate for this species, because of their lower discard probability.

The results of L_{50gear} and $L_{50fisher}$ (or $L_{50discard}$) for the studied species from the published literature and this work are presented in Table 5. Comparisons of L_{50gear} are not straightforward because of the differences in net material, nominal or actual mesh size, the number of mesh sizes in the codend circumference, and several other factors that affect codend selectivity (e.g. Sala and Lucchetti, 2010). However, some of the published parameters are in agreement with our results, particularly when the net characteristics are close to those of the present work (Table 5). Considering the results for $L_{50fisher}$, derived from the applied model and selectivity data as well as those in the literature derived from data from observers onboard fishing vessels, it is worth noting that these were quite comparable in most cases (Table 5). Higher values for some species (e.g. *B. boops, H. dactylopterus, S. smaris*) found in this work may indicate a shift in the selection behaviour of fishers towards larger sizes. This could be attributed to the lower availability of small sizes in the catch associated with the current use of more selective meshes in the trawl codend.

According to the results of this work, the 40S codend is more adequate than the 50D for three of the studied species (*M. poutassou, S. cabrilla, B. boops*). Both codends are appropriate for *S. smaris*. The 50D codend seems more suitable for *C. linguatula*, but still with high discard probability. None of the codends is appropriate for *C. lastoviza* and *H. dactylopterus*. The first four species, characterized by demersal behaviour, a rounded or slightly compressed body with low depth, and a medium to high swimming activity inside the codend during fishing, seem to have advantages for their escapement through the open meshes of the 40S codend. In contrast, flatfish with a high width size receive benefit from the use of 50D meshes, which can be stretched widthwise. *C. lastoviza* and *H. dactylopterus*, characterized by peculiarities in their bodies, benthic behaviour, and low motility inside the net, cannot benefit from any of the tested codends.

Within the framework of the ecosystem approach to fisheries management, and also taking into account the results of other work concerning several species (e.g. *Merluccius merluccius, Mullus barbatus, Nephrops norvegicus, Aristeus antennatus, Phycis blennoides, Trachurus trachurus, Saurida undosquamis;* Özbilgin *et al*., 2012, 2015; Gorelli *et al*., 2014; Dereli and Aydın, 2016; Brčić *et al*., 2018; Mytilineou *et al*., 2018) showing improved selectivity and fewer discards using 40S than 50D, it could be suggested that the 40S codend, although not fully successful, is more sustainable than the 50D for the Mediterranean trawl multispecies fishery. This information is useful in fisheries management, since according to EC Regulation 1967/2006 and REC.CM-GFCM/33/2009/2, the use of 50D in the trawl codend is allowed only if it is more selective than 40S. However, this is only true for flatfish (Sala *et al*., 2008; Özbilgin *et al*., 2012; Mytilineou *et al*., 2018), which do not account for a significant share of the Mediterranean catches (0.56%; FAO statistics 2017). Therefore, unless a modification in the codend is designed to increase the selectivity of 50D, it is necessary to stress the need for a change in the management measures established in the Mediterranean and to initiate discussions with stakeholders with a view to the use of 50D only in areas mainly targeting flatfish and where catches of flatfish are significant.

The model applied in this work was again approved as a useful cost-efficient approach to collecting information for fisheries management since, on the basis of selectivity data, important information on gear selectivity, discards, and fisher behaviour is simultaneously predicted. Moreover, discards and fisher behaviour-related predictions, based on single vessel data, were in accordance with those estimated from fleet-based data in the literature, further confirming the applicability of the model. In the future, more studies are needed for other main commercial and bycatch species and with innovative trawl designs to increase selectivity and reduce the impact of this gear on the stocks in this multispecies fishery.

Supplementary material

The following Supplementary material is available at *ICESJMS* online: description of codend characteristics and estimation of selection parameters as well as Tables S1–S9 and Figures S1–S8.

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Table 1. Number of measured *Micromesistius poutassou, Serranus cabrilla, Boops boops, Trigloporus lastoviza, Helicolenus dactylopterus*, *Citharus linguatula*, and *Spicara smaris* total lengths and their percentage to the total catch in each fraction (E: escapees, D: discards, L: landings) from all hauls conducted with three codends (40D: 40-mm diamond mesh, 40S: 40-mm square mesh, 50D: 50-mm diamond mesh).

Codend	**40D**			**40S**			**50D**		
Compartment / Species	**E**	**D**	**L**	**E**	**D**	**L**	**E**	**D**	**L**
M. poutassou	**584** (49.6%)	**397** (24.4%)	**219** (100%)	**1104** (20.7%)	**59** (61.9%)	**243** (39.2%)	**1267** (14.2%)	**354** (57.7%)	**296** (100%)
S. cabrilla	**59** (98.3%)	**194** (97.5%)	**496** (99.6%)	**481** (99.4%)	**78** (85.7%)	**533** (91.4%)	**355** (99.2%)	**120** (98.4%)	**322** (99.7%)
B. boops	**10** (100%)	**115** (99.1%)	**167** (95.4%)	**275** (48.1%)	**319** (88.5%)	**413** (99.5%)	**540** (95.2%)	**293** (94.5%)	**633** (92.0%)
C. lastoviza	**11** (100%)	**49** (100%)	**92** (100%)	**52** (100%)	**39** (100%)	**78** (100%)	**18** (100%)	**48** (100%)	**127** (100%)
H. dactylopterus	**56** (100%)	**69** (18.9%)	**7** (100%)	**73** (72.3%)	**170** (92.4%)	**14** (100%)	**83** (82.2%)	**196** (100%)	**32** (100%)
C. linguatula	**1225** (76.4%)	**1400** (93.7%)	**21** (100%)	**1108** (64.3%)	**1181** (90.9%)	**6** (100%)	**1617** (52.4%)	**918** (91.3%)	**12** (100%)
S. smaris	**188** (97.4%)	**535** (78.8%)	**132** (100%)	**966** (13.2%)	**677** (31.6%)	**398** (15.1%)	**979** (16.9%)	**768** (61.5%)	**929** (25.1%)

Table 2. Selectivity parameters of *Micromesistius poutassou, Serranus cabrilla*, and *Trigloporus lastoviza* for the overall selection model describing the size-selectivity of the gear ($L50_{gear}$, SR_{gear},$1/\delta_{gear}$), the fisher size-selection ($L50_{fisher}$, SR_{fisher}, $1/\delta_{fisher}$), and the landing probability ($L50_{land}$, SR_{land}) in the trawl codend when using the 40D (40-mm diamond), 40S (40-mm square), and 50D (50-mm diamond) mesh; 95% confidence intervals (*Efron percentile*) are shown in parenthesis; 1/δ is presented in the case of Richard model. (G: gear selectivity model; F: fisher selection model; d.f.: degrees of freedom; AIC: Akaike criterion); $L50_{mat}$: length at first maturity.

			Codend	
Species		**40D**	**40S**	**50D**
			Model	
	Model Parameter	G:G: Richard FF: Richard	G: Richard F: Gompertz	G: Richard F: Logit
Micromesistius poutassou ($L50_{mat}$: 18 cm; Mir-Arguimbau *et al*., 2020)	$L50_{gear}$	10.68 (10.00-12.06)	16.67 (16.22-19.62)	17.05 (15.72-17.99)
	SR_{gear}	4.12 (2.13-6.94)	1.94 (1.39-2.25)	4.21 (2.58-6.22)
	$1/\delta_{gear}$	0.32 (0.10-10.00)	0.76 (0.10-10.00)	1.42 (0.43-10.00)
	$L50_{fisher}$	17.65 (16.57-18.24)	15.23 (14.22-19.06)	16.39 (15.72-17.78)
	SR_{fisher}	2.30 (1.58-3.24)	1.64 (0.10-4.08)	3.21 (1.69-4.40)
	$1/\delta_{gear}$	1.70 (0.72-10.00)		
	$L50_{land}$	17.65 (16.57-18.24)	16.93 (16.57-20.12)	18.21 (17.76-18.78)
	SR_{land}	2.30 (1.58-3.23)	1.75 (1.15-2.70)	3.30 (1.80-4.72)
	p-value	0.4122	0.3657	0.0864
	Deviance	41.33	35.17	58.42
	d.f.	40	33	45
	AIC	3690.35	1270.29	3654.82
			Model	
Serranus cabrilla ($L50_{mat}$:13.2 cm; Ilhan *et al*., 2010)	**Model Parameter**	G: Probit F: Gompertz	G: Probit F: Gompertz	G: Probit F: Gompertz
	$L50_{gear}$	8.39 (6.13-10.03)	13.63 (13.29-14.05)	13.49 (11.66-14.57)
	SR_{gear}	4.65 (3.30-6.69)	2.14 (1.77-2.68)	6.16 (4.44-9.39)
	$L50_{fisher}$	12.72 (12.27-13.11)	12.59 (12.07-13.20)	13.00 (12.48-13.51)
	SR_{fisher}	2.00 (1.65-2.45)	2.14 (1.50-3.03)	2.19 (1.41-3.04)
	$L50_{land}$	12.91 (12.56-13.27)	14.14 (13.82-14.55)	14.75 (14.01-15.32)
	SR_{land}	2.09 (1.73-2.55)	1.97 (1.63-2.44)	3.87 (2.97-5.25)
	p-value	0.9989	0.9360	0.9944
	Deviance	14.16	19.19	12.62
	d.f.	34	30	28
	AIC	840.15	1218.45	1342.60
Boops boops ($L50_{mat}$= 13.8 cm; Kallianiotis, 1992)			**Model**	
	Model Parameter	G: Probit F: Gompertz	G: Probit F: Gompertz	G: Probit F: Logit
	$L50_{gear}$	6.03 (0.10-11.54)	14.37 (13.48-14.61)	13.21 (0.10-15.29)
	SR_{gear}	6.91 (0.10-12.64)	2.13 (1.73-3.14)	8.62 (4.77-36.52)
	$L50_{fisher}$	15.05 (14.33-16.78)	15.35 (14.91-16.33)	14.55 (12.70-15.66)
	SR_{fisher}	2.55 (1.68-3.53)	2.46 (1.76-4.22)	2.29 (1.54-3.77)
	$L50_{land}$	15.14 (14.37-16.85)	15.85 (15.47-16.76)	15.77 (14.68-16.82)
	SR_{land}	2.60 (1.73-3.49)	2.11 (1.66-3.60)	3.76 (2.91-7.34)
	p-value	0.9210	0.9670	0.6366
	Deviance	8.81	10.06	13.49
	d.f.	16	20	16
	AIC	401.48	2135.55	2948.99

Table 3. Overall selection model parameters of *T. lastoviza, H. dactylopterus*, and *C. linguatula* describing the size-selectivity of the gear ($L50_{gear}$, SR_{gear}, $1/\delta_{gear}$), the fisher

size-selection ($L50_{fisher}$, SR_{fisher}, $1/\delta_{fisher}$), and the landing probability ($L50_{land}$, SR_{land}) in the trawl codend with 40D (40-mm diamond), 40S (40-mm square), and 50D (50-mm diamond) mesh; 95% confidence intervals (*Efron percentile*) are shown in parenthesis; 1/δ is presented in the case of Richard model. (G: gear selectivity model; F: fisher selection model; d.f.: degrees of freedom; AIC: Akaike criterion); $L50_{mat}$: Length at first maturity.

			Codend	
Species		**40D**	**40S**	**50D**
Chelidonichthys lastoviza ($L50_{mat}$=15.6 cm; Ben Jrad *et al.*, 2010)	**Model Parameter**	G: Probit F: Gompertz	**Model** G: Richard F: Gompertz	G: Gompertz F: Gompertz
	$L50_{gear}$	5.89 (5.09-8.50)	10.94 (10.03-11.73)	7.82 (6.88-10.19)
	SR_{gear}	1.36 (0.10-2.54)	2.94 (1.78-3.84)	1.94 (0.10-2.72)
	$1/\delta_{gear}$		0.10 (0.10-0.19)	
	$L50_{fisher}$	13.89 (13.02-15.02)	14.28 (13.63-14.96)	14.03 (13.03-15.14)
	SR_{fisher}	2.22 (1.29-3.22)	1.93 (0.85-3.12)	2.56 (1.53-3.69)
	$L50_{land}$	13.89 (13.02-15.02)	14.28 (13.65-14.96)	14.04 (13.05-15.14)
	SR_{land}	2.22 (1.28-3.22)	1.93 (0.85-3.03)	2.55 (1.53-3.68)
	p-value	1.0000	0.9984	1.0000
	Deviance	6.90	22.04	7.74
	d.f.	34	45	38
	AIC	126.02	147.89	138.06
			Model	
Helicolenus dactylopterus ($L50_{mat}$= 14.2 cm; Tsikliras and Stergiou, 2013)	**Model Parameter**	G: Logit F: Logit	G: Richard F: Richard	G: Gompertz F: Probit
	$L50_{gear}$	5.62 (4.98-7.04)	8.68 (7.02-8.99)	7.04 (6.25-7.65)
	SR_{gear}	1.19 (0.10-1.92)	2.59 (0.83-3.78)	3.45 (2.26-4.29)
	$1/\delta_{gear}$		0.10 (0.10-10.00)	
	$L50_{fisher}$	16.80 (14.55-156.76)	16.79 (15.03-17.40)	15.25 (14.62-15.74)
	SR_{fisher}	2.02 (0.10-4.91)	1.11 (0.10-2.34)	1.60 (0.10-2.21)
	$1/\delta_{gear}$		0.10 (0.10-10.00)	
	$L50_{land}$	16.80 (14.55-156.76)	16.79 (15.03-17.40)	15.27 (14.63-15.76)
	SR_{land}	2.02 (0.10-4.91)	1.11 (0.10-2.34)	1.61 (0.10-2.21)
	p-value	0.9946	0.7454	0.9999
	Deviance	15.27	22.75	14.10
	d.f.	32	28	38
	AIC	89.49	231.85	294.64
Citharus linguatula ($L50_{mat}$= 15 cm; Cengiz *et al.*, 2014)			**Model**	
	Model Parameter	G: Richard F: Probit	G: Richard F: Gompertz	G: Richard F: Richard
	$L50_{gear}$	10.00 (8.91-10.83)	10.41 (10.06-10.72)	13.89 (12.37-16.15)
	SR_{gear}	4.65 (3.70-6.25)	1.78 (1.57-2.04)	4.64 (3.51-6.81)
	$1/\delta_{gear}$	0.12 (0.10-0.30)	0.19 (0.10-0.39)	0.10 (0.10-0.76)
	$L50_{fisher}$	17.85 (17.18-110.10)	19.38 (17.99-181.36)	18.51 (17.97-19.28)
	SR_{fisher}	1.65 (0.10-2.80)	2.22 (0.10-36.47)	0.71 (0.10-2.13)
	$1/\delta_{gear}$			0.10 (0.10-10.00)
	$L50_{land}$	17.85 (17.18-110.10)	19.38 (17.99-181.36)	18.52 (18.02-19.36)
	SR_{land}	1.65 (0.10-2.80)	2.22 (0.10-36.46)	0.71 (0.10-2.13)
	p-value	1.0000	0.9900	0.9829
	Deviance	8.18	15.66	18.91
	d.f.	29	31	34
	AIC	3462.03	2021.84	4180.15

Table 4. Selectivity parameters of *Spicara smaris* for the overall selection model describing the size-selectivity of the gear ($L50_{gear}$, SR_{gear}), the fisher size-selection ($L50_{fisher}$, SR_{fisher}), and the landing probability ($L50_{land}$, SR_{land}) in the trawl codend when using the 40D (40-mm diamond), 40S (40-mm square), and 50D (50-mm

diamond) mesh; 95% confidence intervals (*Efron percentile*) are shown in parenthesis; 1/δ is presented in the case of Richard model. (G: gear selectivity model; F: fisher selection model; d.f.: degrees of freedom; AIC: Akaike criterion); $L50_{mat}$: length at first maturity.

			Codend	
Species		**40D**	**40S**	**50D**
Spicara smaris ($L50_{mat}$= 9 cm; Vidalis, 1994)	**Model Parameter**	G:G: Gompertz FF: Probit	**Model** G: Gompertz F: Gompertz	G: Gompertz F: Gompertz
	$L50_{gear}$	7.56 (0.10-10.98)	12.71 (12.39-14.63)	12.70 (11.63-13.48)
	SR_{gear}	7.78 (3.02-18.97)	4.09 (3.46-11.65)	3.17 (2.49-6.09)
	$L50_{fisher}$	10.24 (0.10-12.34)	13.60 (9.32-13.84)	15.15 (14.06-16.91)
	SR_{fisher}	-3.38 (-12.01- -0.10)	-1.65 (-6.58- -1.21)	-2.74 (-3.57- -1.74)
	$L50_{disc}$	11.28 (8.57-12.53)	14.27 (13.75-15.72)	15.59 (14.80-17.20)
	SR_{disc}	3.38 (2.66-6.75)	1.92 (1.55-10.26)	2.47 (1.69-3.25)
	p-value	0.2759	<0.0005	<0.0005
	Deviance	18.86	116.32	146.52
	d.f.	16	22	16
	AIC	1447.85	16509.99	17354.12

Table 5. L_{50gear} (length at which 50% of the individuals are retained by the trawl codend) and $L_{50fisher}$ (length at which 50% of the retained in the codend individuals are discarded by the fisher) published in the literature for the studied in the present work species from the Mediterranean Sea. The results of the present work are also presented. Mesh characteristics are also given.

Species	**Mesh**	L_{50gear} **(cm TL)**	$L_{50fisher/discard}$ **(cm TL)**	**Reference**	**Area**
M. poutassou	40D	21.17		Petrakis and Stergiou (1997)	W. Aegean Sea
	40S	16.96			
	40D280_PA*	10.92		Sala and Lucchetti (2010)	Adriatic Sea
	40D326_PA	10.62			
	40S70_PA	13.58			
	40D300_PE	18.75		Tokaç *et al.* (2010)	E. Aegean Sea
	40D150_40S75_PE	19.42			
	40D400_PA	10.68		Present work	S. Aegean Sea
	50D340_PA	17.05			
	40S200_PA	16.67			
	40D		10.6–22.3	Tsagarakis *et al.* (2017)	Mediterranean
	40D400_PA		17.65	Present work	S. Aegean Sea
	50D340_PA		16.39		
	40S200_PA		15.23		
S. cabrilla	40D_PE	9.3		Ordines *et al.* (2006)	Balearic Isl.
	40S_PE	14.1			
	40D400_PA	8.39		Present work	S. Aegean Sea
	50D340_PA	13.49			
	40S200_PA	13.63			
	28D		12.9	Machias *et al.* (2004)	E. Ionian Sea
			17.8		Cyclades Isl.
	40D400_PA		12.72	Present work	S. Aegean Sea
	50D340_PA		13.00		
	40S200_PA		12.59		
B. boops	44D_PA	14.2		Ateş *et al.* (2010)	Antalya Bay (Levantine Sea)
	40S_PE	17.5			
	44D300_PE	6.81		Eryaşar *et al.* (2014)	Mersin Bay (Levantine Sea)
	44D150_PE	7.56			
	44D300_PE	13.2		Ilkyaz *et al.* (2017)	Mersin Bay (Levantine Sea)
	44D150_PE	13.8			
	44(T90)165_PE	12.7			
	40D400_PA	6.03		Present work	S. Aegean Sea
	50D340_PA	13.21			
	40S200_PA	14.37			
	28D		11.7–12.3	Machias *et al.* (2004)	E. Ionian Sea
	40D		12.9	Damalas *et al.* (2018)	Aegean Sea
	40D / 40S		13.6		
	40D400_PA		15.05	Present work	S. Aegean Sea
	50D340_PA		14.55		
	40S200_PA		15.35		
C. lastoviza	40D_PE	4.7		Ordines *et al.* (2006)	Balearic Isl.
	40S_PE	7.3			
	40D400_PA	5.89		Present work	S. Aegean Sea
	50D340_PA	7.82			
	40S200_PA	10.94			
	28D		14.7–17.3	Machias *et al.* (2004)	E. Ionian Sea
	40D400_PA		13.89	Present work	S. Aegean Sea
	50D340_PA		14.03		
	40S200_PA		14.28		
H. dactylopterus	40D	5.52		D'Onghia *et al.* (2003)	N. Ionian Sea
	50D	7.46			
	60D	11.85			
	40S_PE	10.9		Ordines *et al.* (2006)	Balearic Isl.
	40D300_PE	7.7		Tokaç *et al.* (2010)	E. Aegean Sea
	40D150_40S75_PE	10.36			
	40D300_PE	7.91		Özbilgin et al. (2012)	E. Aegean Sea
	48D275_PE	9.48			
	40S150_PE	9.88			
	40D400_PA	5.62		Present work	S. Aegean Sea
	50D340_PA	7.04			
	40S200_PA	8.68			
	28D		12.7–13.6	Machias *et al.* (2004)	E. Ionian Sea
	40D400_PA		16.80	Present work	S. Aegean Sea
	50D340_PA		15.25		

	40S200_PA		16.79		
C. linguatula	40S_PE	11.5		Ordines *et al.* (2006)	Balearic Isl.
	36S_PE	9.27		Sardà *et al.* (2006)	Catalan Sea
	40D400_PA 50D340_PA 40S200_PA	10.00 13.89 10.41		Present work	S. Aegean Sea
	28D		17.5–18.6	Machias *et al.* (2004)	E. Ionian Sea
	40D400_PA 50D340_PA 40S200_PA		17.85 18.52 19.38	Present work	S. Aegean Sea
S. smaris	40D_PE 40S_PE	9.0 17.1		Ordines *et al.* (2006)	Balearic Isl.
	44D300_PE 44D150_PE	7.82 10.18		Eryaşar *et al.* (2014)	Mersin Bay (Levantine Sea)
	40D400_PA 50D340_PA 40S200_PA	7.56 12.70 12.71		Present work	S. Aegean Sea
	28D		9.4–10.5	Machias *et al.* (2004)	E. Ionian Sea
	40D400_PA 50D340_PA 40S200_PA		10.24 15.15 13.60	Present work	S. Aegean Sea

* Mesh description:(i) mesh size in mm, (ii) mesh configuration (D: diamond, S: square, T90: turned), (iii) number of meshes in codend circumference,(iv) twine material (PA: polyamide, PE: polyethylene).

Captions of Figures

Figure 1. Map of the study area, indicating the hauls (red diamonds) of the experimental fishing; isobaths 50, 100, and 300 m: dots, continuous, dashed lines, respectively.

Figure 2. Size-selection curves for *Micromesistius poutassou, Serranus cabrilla*, and *Boops boops* when using 40-mm diamond (40D), 40-mm square (40S), and 50-mm diamond (50D) meshes in the trawl codend. Blue, grey, and red curves: escape (p_{esc}), discard (p_{disc}), and landing probability (p_{land}), respectively; triangles, crosses, and dots: the associated experimental ratios, respectively. Coloured areas around the curves: Efron percentile 95% confidence intervals. The length at first maturity of the species is also shown as a black bar in each plot.

Figure 3. Size-selection curves for *Chelidonichthys lastoviza, Helicolenus dactylopterus*, and *Citharus linguatula* when using 40-mm diamond (40D), 40-mm square (40S), and 50-mm diamond (50D) meshes in the trawl codend. Blue, grey, and red curves: escape (p_{esc}), discard (p_{disc}), and landing probability (p_{land}), respectively; triangles, crosses, and dots: the associated experimental ratios, respectively. Coloured areas around the curves: Efron percentile 95% confidence intervals. The length at first maturity of the species is also shown as a black bar in each plot.

Figure 4. Size-selection curves for *Spicara smaris* when using 40-mm diamond (40D), 40-mm square (40S), and 50-mm diamond (50D) meshes in the trawl codend. Blue, grey, and red curves: escape (p_{esc}), discard (p_{disc}), and landing probability (p_{land}), respectively; triangles, crosses, and dots: the associated experimental ratios, respectively. Coloured areas around the curves: Efron percentile 95% confidence intervals. The length at first maturity of the species is also shown as a black bar in each plot.