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Estimating overall size-selection pattern in the bottom trawl fishery for four economically important fish species in the Mediterranean Sea

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ABSTRACT

The management of multispecies fisheries, such as the Mediterranean bottom trawl fishery, is always a challenge. However, information on gear selectivity and discards has been studied separately so far. In this paper, the overall size-selection pattern by the trawl codend in the sea and by the fisher onboard the vessel is investigated for four commercially important fish species, *Mullus barbatus, Mullus surmuletus*, *Pagellus erythrinus* and *Lophius budegassa*, using different codends. For each species, the selection model used offered the possibility to simultaneously describe the escape, discard, and landing probability. The results, useful for fisheries management, showed that the codend made of 40 mm diamond meshes was always detrimental for the stocks. The 40 mm square meshes codend compared to that of 50 mm diamond meshes was more appropriate for the sustainability of both *Mullus* species, providing also a lawful catch along with greater compliance to the rules fisher behaviour, negligible discards and the lowest possible economic losses for the fisher. None of the codends was effective for *P. erythrinus* in achieving the minimum conservation reference size (MCRS) of the species. All codends were harmful to *L. budegassa* as the majority of juveniles were retained in the codend, resulting in negligible escapees, a high discard probability, and landings of a size much lower than the length at first maturity of the species. Further studies are needed to be conducted in the future for other species, since the trawl fishery in the Mediterranean is a multi-species fishery.

1. Introduction

The Mediterranean trawl fishery primarily targets species of high economic importance, such as hake (*Merluccius merluccius*), mullets (*Mullus* spp.), common pandora (*Pagellus erythrinus*) and blackbellied anglerfish (*Lophius budegassa*). Bycatch of juveniles of these species ends up discarded (Tsagarakis et al., 2017; Bellido et al., 2017; Mytilineou et al., 2018; 2020). Juvenile protection and the reduction of undersized catch below the minimum conservation reference size (MCRS) are important issues in the European Common Fishery Policy, particularly related to the management of the Mediterranean bottom trawl fishery (Council Regulation (EC) No 1967/2006; Regulation (EU) 2019/1241). Gear and fisher selection patterns are related to these issues affecting stock sustainability (Vasilakopoulos et al., 2015). Although gear selectivity and discard probability have generally been studied separately, Mytilineou et al. (2018) combined these two sequential selection processes and modelled for the first time the overall selection process on a fish population entering the trawl codend. This approach first applied for European hake, Atlantic horse mackerel and four-spotted megrim, and based on selectivity data, simultaneously predicts the escape, discard, and landing probability of the species studied. As the Mediterranean trawl fishery is a multispecies one, such information is essential for all target species, especially under the state of overexploitation of most stocks in the Mediterranean (FAO, 2020).

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In the Mediterranean, many studies have been conducted for the trawl codend selectivity of red mullet (e.g. Tokaç et al., 2014; Sala et al., 2015) and common pandora (e.g. Ateş et al., 2010; Özbilgin et al., 2012); only one for striped mullet (Ordines et al., 2006) and none for blackbellied anglerfish. On the other hand, several studies on the discard probability of these species have been conducted, based on data from observers onboard fishing vessels (e.g. Tsagarakis et al., 2017; Damalas et al., 2018). To date, no research has provided combined information on the overall selection of these species for the Mediterranean trawl fishery.

The objective of this study is twofold: i) to investigate the potential applicability of the model proposed by Mytilineou et al. (2018) based on the population of red mullet (*Mullus barbatus*), striped mullet (*Mullus surmuletus*), common pandora (*Pagellus erythrinus*) and blackbellied anglerfish (*Lophius budegassa*) entering the trawl codend and ii) to study the overall size-selection for these commercially important species and provide information on their escape, discard and landing probability.

2. Materials and methods

2.1. Data collection

From September 9 to October 4, 2014, a selectivity experimental survey was conducted on fishing grounds of the South Aegean Sea (Fig. 1, for details Table S1 in Supplementary material). For this purpose, a commercial trawler, equipped with a bottom trawl used in professional fishing, was hired. The specifications of the gear are described in detail in the Supplementary material as well as in Mytilineou et al. (2018). The depth range of the experimental fishing was between 50 and 310 m, in line with the main depth range in which the commercial Greek trawl fleet operates. Fishing was carried out in 28 locations using three different codends resulting in a total of 84 hauls (3 × 28). Invalid hauls due to damaged net or poor gear performance during fishing, which was checked by SCANMAR, were excluded from the analysis.

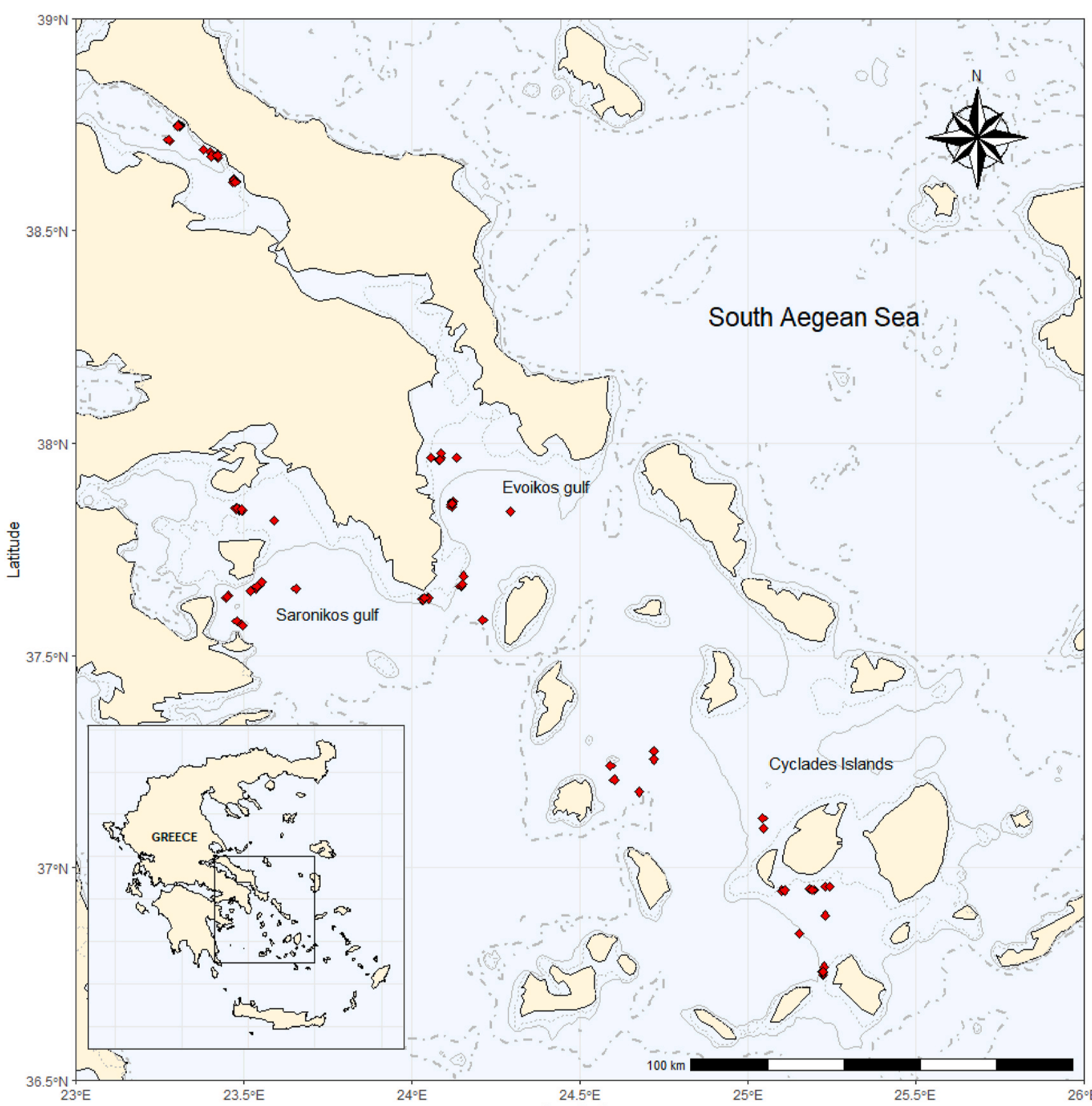

Fig. 1. Map of the study area, where the hauls (red diamonds) of the experimental fishing were conducted; isobath 50 m: dots line, isobath 100 m: continuous line, isobath 300 m: dashed line. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Three codends were used to conduct the experimental fishing survey: i) a codend of 40 mm nominal size square meshes (40S), which has been established in the commercial Mediterranean trawl fishery according to the Council Regulation (EC) No 1967/2006 (actual mesh size: 43.2 ± 0.6 mm), (ii) a codend of 50 mm nominal size diamond meshes (50D), which can be used in accordance to the above-mentioned regulation, if it is more selective than the 40S (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 latter, although prohibited in EU Mediterranean countries, was investigated because smaller or slightly larger meshes are still in use in various Mediterranean trawl fleets (e.g. Ragheb et al., 2019). In all cases, the three codends were 5.6 m in length, and with the same circumferential length at sea (~4.3 m). They were knotless, and made by single twine multifilament nylon (PA) of 2.8 mm twine thickness. The number of meshes in codend circumference was 400, 200, and 340 meshes for the 40D, the 40S, and 50D, respectively. The characteristics of the three codends and their meshes are described in detail in the Supplementary material (Table S2).

Data were collected for four species, red mullet *M. barbatus* Linnaeus, 1758, striped mullet *M. surmuletus* Linnaeus, 1758, common pandora *P. erythrinus* (Linnaeus, 1758) and blackbellied anglerfish *L. budegassa* Spinola, 1807, which were selected for their commercial importance and high economic value, and therefore the need of information for their sustainable exploitation and management. *M. barbatus M. surmuletus, P. erythrinus* and *L. budegassa* are species with different body shape characteristics; the first two of rounded body shape, the third one very compressed and of high body depth, and the last one with a very large head. Furthermore, the first three species are regulated with MCRS at 11 cm, 11 cm and 15 cm, respectively (Council Regulation (EC) No 1967/2006; Regulation (EU) 2019/1241). *L. budegassa,* although regulated in the past with MCRS at 30 cm TL (Council Regulation (EC) No 1626/94), is no longer part of any new regulation nowadays. Moreover, a policy reform of the legislated discard ban, permitted *M. barbatus* discarding up to 6% of the total annual landings of the species by 2019 (Commission Delegated Regulation (Eu) 2017/86). Apart from the MCRS, the length at first maturity of these species, available in the literature, was also used as a threshold for the sustainable exploitation of their stocks by the trawl.

A three-compartment sampling scheme was used to classify escapees, discards, and landings as described in Mytilineou et al. (2018). The cover-codend method (Wileman et al., 1996) was used to collect the data for the escapees. The design for the cover was similar to that presented by Sala et al. (2015) using in the cover a 20-mm diamond mesh size net. During the process, escapees were retained in the cover, while the separation between discards and landings as well as the classification of the landings compartment into different commercial categories was performed by the vessel crew simulating the procedure followed in commercial fishing. The landings compartment, depending on the species, was divided into two or three compartments according to their size related commercial value (i.e category A, B, and C) for further analyses.

2.2. Predicting the overall size-selection process

The methodological approach for modelling the sequential size-selection processes, both in the sea and onboard the fishing vessel, is described in detail in Mytilineou et al. (2018). In summary, a fish of length $\boldsymbol{l}$ after entering the gear in the sea has a probability $\boldsymbol{p_{esc}}$ to escape through the codend, or equivalently:

$$p_{esc}(l) = 1 - r_{gear}(l)$$

where $\boldsymbol{r_{gear}}$ is the probability of a fish to be retained by the gear. Then, given that the fish is retained, it has a probability $\boldsymbol{p_{land}}$ to be landed by the fisher. Denoting by $\boldsymbol{r_{fisher}}$, the probability of a retained by the gear fish being retained by the fisher and landed, we have:

$$p_{land}(l) = r_{gear}(l) \text{ x } r_{fisher}(l)$$

We then denote by $\boldsymbol{p_{disc}}$ the probability of a fish to be discarded by the fisher, given that it has been retained by the gear. The mathematical formulation of this process can be described as follows:

$$p_{disc}(l) = (1 - r_{fisher}(l)) \text{ x } r_{gear}(l)$$

Since both probabilities, $\boldsymbol{p_{esc}}$ and $\boldsymbol{p_{land}}$ can be interpreted as size selection procedures and given that in most cases smaller fish are being discarded, their probabilities are represented by sigmoid curves, while the $\boldsymbol{p_{disc}}$ is fitted by a bell-shaped curve.

Following Wileman et al. (1996), selection curves can be adequately described by four different models: Logit, Probit, Gombertz and Richard. In the present analysis, the four models were fitted to the data of each sequential selection process $\boldsymbol{r_{gear}}$ and $\boldsymbol{r_{fisher}}$. A total of 16 different combinations of models were tested for each codend. The best model was selected based on the p-value (should be > 0.05) as well as the model deviance compared to the degrees of freedom (Wileman et al., 1996), followed by the AIC criterion (Akaike, 1974). These models are described by a set of parameters: the length at which 50% of the fish is being retained either by the codend or the fisher, denoted as $\boldsymbol{L50_{gear}}$ and $\boldsymbol{L50_{fisher}}$ respectively, the selection range $\boldsymbol{SR_{gear}}$ and $\boldsymbol{SR_{fisher}}$ (denoted as the difference *L75 - L25*) and in the case of Richard model an additional parameter $\boldsymbol{\delta}$, which describes the asymmetry of the curve. Let $\boldsymbol{\nu}$ denote the set of parameters for each model. Then the probabilities of $\boldsymbol{r_{gear}}$ and $\boldsymbol{r_{fisher}}$ can be expressed as:

$$r_{gear}\ (l,\ \nu_{gear}) \text{ and } r_{fisher}\ (l,\ \nu_{fisher})$$

Since the probability $\boldsymbol{p_{land}}$ is expressed by the two curves $\boldsymbol{r_{gear}}$ and $\boldsymbol{r_{fisher}}$, the parameters $\boldsymbol{L50_{land}}$ and $\boldsymbol{SR_{land}}$ can also be estimated. This method was described in Sistiaga et al. (2010). Parameter estimation for the three different probabilities: $\boldsymbol{p_{esc}}$, $\boldsymbol{p_{disc}}$ and $\boldsymbol{p_{land}}$ was performed using the maximum log-likelihood function as applied by Mytilineou et al. (2018). Although a mean selection curve is generally estimated on individual haul basis (Fryer, 1991), in the present study average selection parameters were estimated for each codend by pooling the data of the hauls, as proposed by Millar (1993) for fisheries. However here, the three compartments design was considered for the two sequential selection processes of the overall selection model (see equation described in Mytilineou et al., 2018). Besides the average selectivity curve, a bootstrap technique was applied to calculate the *"Efron percentile 95% confidence limits"* (95% CI) for this curve (Efron, 1982), taking into account both within and between haul variation (Millar, 1993). All the analysis described above was implemented using SELNET software (Hermann et al. 2012; 2013) and applied in several works (Sala et al., 2015; Mytilineou et al., 2018; Herrmann et al., 2019).

2.3. Comparisons between gears

The parameters of the three codends were compared through the overlapping of their estimated 95% CIs (Frandsen et al., 2010). Furthermore, length-depended differences between the three condends were calculated for the probabilities $\boldsymbol{p_{esc}}$, $\boldsymbol{p_{disc}}$, and $\boldsymbol{p_{land}}$ using the following formulas:

$$\Delta p_{esc}(l) = p_{esc\_i}(l) - p_{esc\_j}(l)$$

$$\Delta p_{disc}(l) = p_{disc\_i}(l) - p_{disc\_j}(l)$$

$$\Delta p_{land}(l) = p_{land\_i}(l) - p_{land\_j}(l)$$

where $\boldsymbol{l}$ is the length class and $\boldsymbol{j}$, $\boldsymbol{i}$ = ***(40D, 40S, 50D)*** with $i \neq j$. The differences were accompanied by their related Efron 95% confidence limits. In the case that the 95% CI of a length class includes zero, the difference is not statistically significant. The method was applied by several researchers (Larsen et al., 2018; Mytilineou et al., 2020).

2.4. Discard indicators

Discard indicators proposed by Mytilineou et al. (2018) were also estimated in this work. Specifically: $\boldsymbol{LDp_{max}}$ is the length at which the probability of a fish to be discarded is the highest, denoted as $\boldsymbol{Dp_{max}}$; $\boldsymbol{DR_{0.05}}$, $\boldsymbol{DR_{0.25}}$, $\boldsymbol{DR_{0.50}}$, $\boldsymbol{DR_{0.75}}$, $\boldsymbol{DR_{0.95}}$ are the different ranges of the discard bell-shaped curve at different levels of probability and $\boldsymbol{DA_{0.05}}$ is the surface of the discard bell-shaped curve when the probability is ≥ 0.05 (for details see Fig. 3 in Mytilineou et al., 2018).

3. Results

3.1. Experimental data

Data for *M. barbatus, M. surmuletus, P. erythrinus* and *L. budegassa* collected during the experimental survey per haul and in total for the three compartments, the escapees, the discards, and the landings for each codend and their percentage to the total amount of the species entering the trawl codend are presented in Tables S3-S6 in the Supplementary material. Both *M. barbatus* and *M. surmuletus* were caught in many hauls (18 and 12, respectively) and in high numbers (Table S3 and S4). *P. erythrinus,* although being fished in 8 of the hauls, was also collected in high numbers (Table S5). *L. budegassa* was caught in 9 of the hauls, but in very low numbers, reflecting the generally low abundance of the species in the sea (Table S6).

3.2. Mullus barbatus

The parameters and the statistics for the best overall selection model of *M. barbatus* appear in Table 1. The model fitted the data well in all cases (Fig. 2).

The $L50_{gear}$ of *M. barbatus* was significantly higher for the 40S than for the two diamond codends. Similar $L50_{gear}$ with overlap of their 95% CI was found for the 40D and 50D (Table 1). Significantly higher escape probability was detected for the 40S and 50D compared to 40D mainly for lengths ranging between 9 - 17 cm and 11–23 cm TL, respectively (Fig. 3). The escape probability of the 50D compared to 40S was significantly lower for lengths 9–13 cm, but significantly higher for lengths ≥17 cm TL (Fig. 3), related to the higher SR_{gear} value of the 50D (Table 1).

The discard probability showed relatively low values in all cases (Fig. 2), indicating that a few *M. barbatus* entering the three codends will be discarded. Statistically significant higher discard probability for the 40D and 50D compared to the 40S was predicted for the sizes ≥12 cm TL; however, of negligible importance (Fig. 3). The 40S codend showed the lowest discard indicators with Dp_{max} at 0.06 and $DA_{0.05}$ almost zero, but an overlap of the 95% CI was detected for all of them among the three codends (Table 2).

$L50_{land}$ of *M. barbatus* was significantly higher for the 40S and lower for the 40D (Table 1); an overlap of the 95% CI of the latter was found with that of 50D. Fisher landing probability displayed significantly

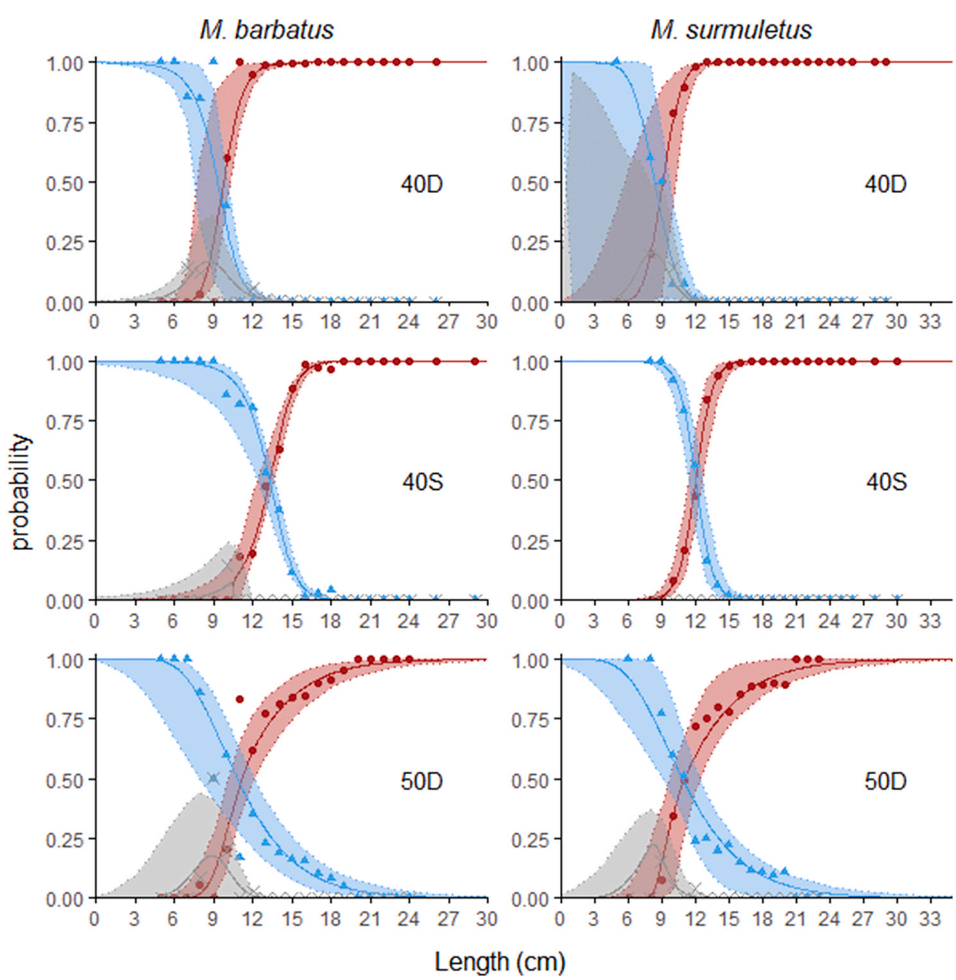

Fig. 2. Size-selection curves for *Mullus barbatus* and *Mullus surmuletus* when using 40 mm diamond mesh (40D), 40 mm square mesh (40S) or 50 mm diamond mesh (50D) in the trawl codend. Blue curves and triangles: gear escape probability (p_{esc}) and associated experimental ratios; grey curves and crosses: discard probability (p_{disc}) and associated experimental ratios; red curves and dots: landing probability (p_{land}) and associated experimental ratios. Coloured areas around the curves: Efron percentile 95% confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

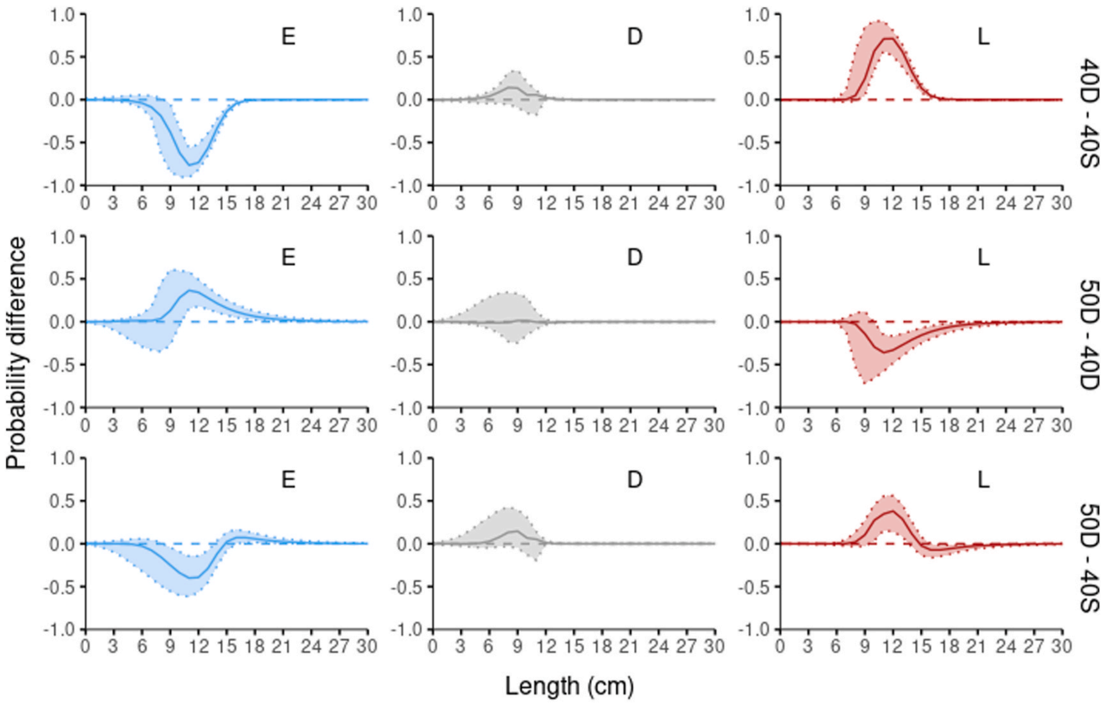

Fig. 3. Difference in the *Mullus barbatus* size-dependent escape (E), discard (D) and landing probability (L) (in blue, grey and red colour, respectively) between 40D - 40S, 50D - 40D and 50D – 40S codends. 40D, 40S, 50D: trawl codend with 40 mm diamond mesh, 40 mm square mesh, 50 mm diamond mesh, respectively; coloured areas around lines: 95% Efron percentile confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1

Selectivity parameters for *Mullus barbatus* and *Mullus surmuletus* 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) or 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; DOF: degrees of freedom; AIC: Akaike criterion).

Species		Codend		
		40D	40S	50D
Mullus barbatus	**Model Parameter**	**Model** G:G: Richard F: Gompertz	G: Richard F: Logit	G: Gompertz F: Probit
	$L50_{gear}$	9.34 (7.77–10.04)	13.31 (12.36–13.68)	10.83 (7.94–12.13)
	SR_{gear}	2.00 (0.47–2.49)	2.23 (1.83–3.97)	4.73 (3.44–7.19)
	$1/\delta_{gear}$	0.58 (0.10–10.00)	0.56 (0.15–1.40)	
	$L50_{fisher}$	8.71 (0.10–9.45)	10.48 (0.10–11.73)	9.41 (0.10–10.34)
	SR_{fisher}	1.53 (1.04–4.08)	0.10 (0.10–0.10)	1.67 (0.10–2.29)
	$L50_{land}$	9.80 (7.94–10.26)	13.31 (12.36–13.68)	11.19 (10.15–12.18)
	SR_{land}	1.61 (0.59–1.91)	2.23 (1.83–3.97)	3.60 (2.27–5.14)
	p-value	0.2169	0.2589	0.3711
	Deviance	43.41	44.27	38.17
	DOF	37	39	36
	AIC	421.87	2668.21	2248.49
Mullus surmuletus	**Model Parameter**	**Model** G: Probit F: Probit	G: Logit F: Logit	G: Gompertz F: Gompertz
	$L50_{gear}$	8.40 (0.10–9.69)	12.04 (11.37–12.63)	10.84 (9.02–12.35)
	SR_{gear}	2.20 (0.10–4.72)	1.65 (1.17–2.05)	5.81 (2.49–8.42)
	$L50_{fisher}$	8.05 (4.10–9.90)	–	9.08 (0.10–10.27)
	SR_{fisher}	2.10 (0.20–3.84)	–	1.09 (0.10–1.82)
	$L50_{land}$	9.10 (5.69–10.16)	12.04 (11.37–12.63)	11.06 (9.55–12.45)
	SR_{land}	1.78 (0.47–3.54)	1.65 (1.17–2.05)	4.61 (2.33–5.94)
	p-value	1.0000	1.0000	0.9998
	Deviance	7.47	2.72	9.98
	DOF	40	38	30
	AIC	136.19	211.46	486.08

Table 2
Discard parameters (with confidence intervals) based on the best model for the overall size-selection process by the gear and the fisher; $DR_{0.05}$, $DR_{0.25}$, $DR_{0.5}$, $DR_{0.75}$. $DR_{0.95}$: discard range (cm) at several probability levels, Dpmax: maximum discard probability value, LDpmax: length (cm) at the maximum discard probability and $DA_{0.05}$: surface of the discard bell-shaped curve when probability ≥0.05.

Species	CODEND			
	Parameter	40D	40S	50D
Mullus barbatus	$DR_{0.05}$	5.05 (0.00–6.61)	0.49 (0.00–7.02)	4.68 (0.00–9.81)
	$DR_{0.25}$	0.00 (0.00–2.12)	0.00 (0.00–0.20)	0.00 (0.00–5.05)
	$DR_{0.5}$	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
	$DR_{0.75}$	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
	$DR_{0.95}$	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
	Dpmax	0.17 (0.01–0.39)	0.06 (0.00–0.27)	0.18 (0.00–0.46)
	LDpmax	8.65 (7.57–10.77)	9.83 (0.00–10.73)	8.87 (0.00–9.64)
	$DA_{0.05}$	0.57 (0.00–1.16)	0.00 (0.00–0.93)	0.55 (0.00–2.56)
Mullus surmuletus	$DR_{0.05}$	4.93 (1.32–10.60)	0.00 (0.00–0.00)	5.04 (0.00–8.80)
	$DR_{0.25}$	0.00 (0.00–7.79)	0.00 (0.00–0.00)	0.00 (0.00–3.22)
	$DR_{0.5}$	0.00 (0.00–5.83)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
	$DR_{0.75}$	0.00 (0.00–3.41)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
	$DR_{0.95}$	0.00 (0.00–0.35)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
	Dpmax	0.21 (0.06–1.00)	0.00 (0.00–0.00)	0.22 (0.00–0.40)
	LDpmax	8.15 (1.47–9.36)	0.00 (0.00–0.00)	8.14 (0.00–9.87)
	$DA_{0.05}$	0.66 (0.07–3.41)	0.00 (0.00–0.00)	0.66 (0.00–1.79)
Pagellus erythrinus	$DR_{0.05}$	10.59 (6.00–15.29)	6.18 (0.00–7.00)	7.11 (1.95–13.98)
	$DR_{0.25}$	4.95 (3.60–13.08)	3.49 (0.00–4.49)	0.23 (0.00–5.21)
	$DR_{0.5}$	2.16 (1.19–11.46)	0.69 (0.00–2.64)	0.00 (0.00–0.35)
	$DR_{0.75}$	0.00 (0.00–9.78)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
	$DR_{0.95}$	0.00 (0.00–7.37)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
	Dpmax	0.65 (0.56–1.00)	0.54 (0.02–0.72)	0.26 (0.07–0.49)
	LDpmax	11.00 (1.50–11.97)	11.78 (11.29–13.43)	11.76 (10.99–12.73)
	$DA_{0.05}$	2.99 (2.16–8.37)	1.80 (0.00–2.66)	1.00 (0.12–3.22)
Lophius budegassa	$DR_{0.05}$	21.02 (17.13–24.61)	24.96 (13.59–26.26)	25.96 (20.22–31.85)
	$DR_{0.25}$	15.61 (12.81–20.92)	21.93 (11.43–24.25)	20.57 (16.28–27.24)
	$DR_{0.5}$	12.36 (10.12–19.13)	17.82 (9.71–23.05)	16.83 (13.63–23.93)
	$DR_{0.75}$	9.42 (7.59–17.38)	13.73 (7.64–22.52)	13.12 (10.66–20.69)
	$DR_{0.95}$	5.51 (4.01–15.69)	7.78 (2.27–22.10)	7.81 (5.75–17.08)
	Dpmax	1.00 (1.00–1.00)	1.00 (0.96–1.00)	1.00 (0.99–1.00)
	LDpmax	12.65 (1.50–13.51)	16.83 (1.50–22.50)	12.44 (1.50–14.14)
	$DA_{0.05}$	12.55 (10.24–18.86)	17.42 (9.67–21.33)	16.71 (13.55–22.81)

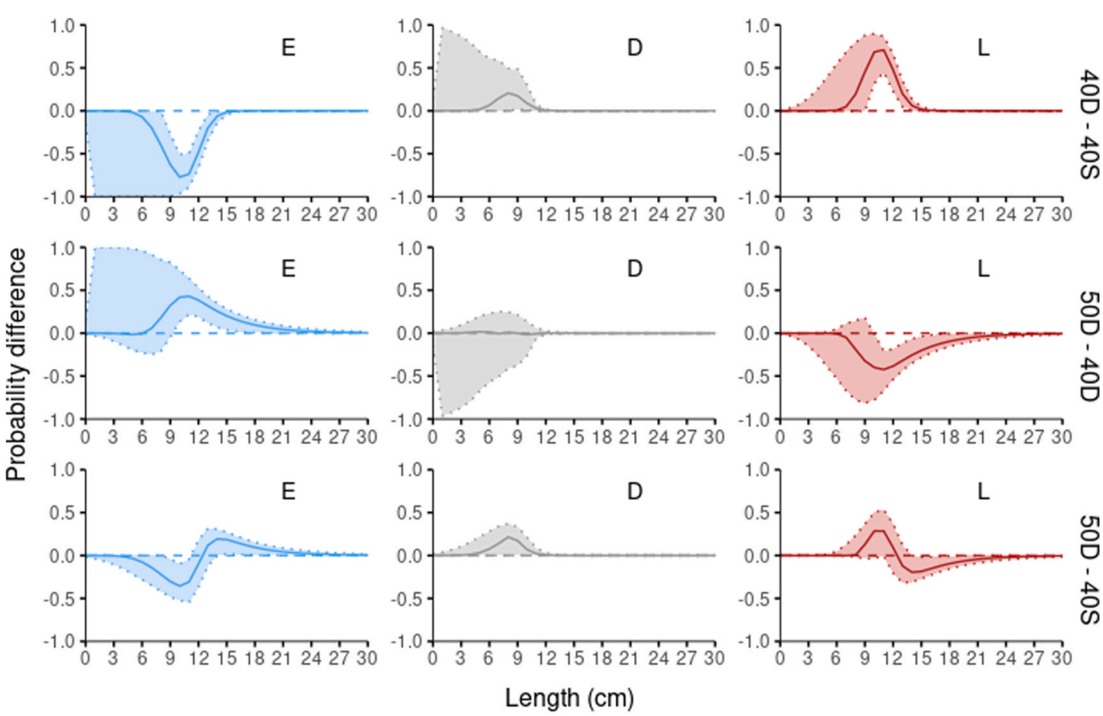

Fig. 4. Difference in the *Mullus surmuletus* size-dependent escape (E), discard (D) and landing probability (L) (in blue, grey and red colour, respectively) between 40D - 40S, 50D - 40D and 50D – 40S codends. 40D, 40S, 50D: trawl codend with 40 mm diamond mesh, 40 mm square mesh, 50 mm diamond mesh, respectively; coloured areas around lines: 95% Efron percentile confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

higher values for the 40D than the 40S at lengths 9–18 cm TL (most important between 9 and 15 cm); higher for the 40D than 50D at lengths ≥10 cm TL (most important between 10 and 20 cm). Landing probability was also higher for the 50D than 40S for the sizes 10–13 cm TL, but higher for the 40S than 50D at sizes ≥17 cm TL (Figs. 2 and 3).

3.3. *Mullus surmuletus*

The overall selection model fitted the data of *M. surmuletus* well, although the very small number of individuals and the absence of some size classes in the 40D escapees and discards produced large 95% CI (Fig. 2). The results for the best model appear in Table 1.

$L50_{gear}$ of *M. surmuletus* was significantly higher for the 40S than the other two codends. Overlap of their 95% CI was found for the 40D and 50D (Table 1). A significantly higher escape probability was detected for the 40S and the 50D compared to 40D, mainly for lengths between 8 - 15 cm and 10 – 25 cm TL, respectively (Fig. 4). The escape probability of the 50D codend compared to 40S was significantly lower for lengths 8 – 11 cm, but significantly higher especially for lengths 15 - 25 cm TL (Fig. 4), which is related to the higher SR_{gear} value of the 50D (Table 1).

The discard probability of *M. surmuletus* was significantly higher for the two diamond codends than the 40S one; the latter without discards (Fig. 2). Statistically significant higher discard probability for the 40D and 50D compared to 40S was predicted for the sizes 5 – 11 cm TL; no significant difference between the diamond codends (Fig. 4). Similar indicators were obvious for the 40D and 50D, which differed significantly from the zero values of 40S (Table 2).

The parameter $L50_{land}$ was significantly higher for the 40S and lower for the 40D (Table 1). An overlap of the 95% CI of the latter was observed with that of the 50D. Fisher landing selection displayed significantly higher values for the 40D than the 40S or 50D at lengths >10 cm (most important between 10 and 15 cm). It was higher for the 50D than 40S only for the size 11 cm TL, but higher for the 40S than 50D at sizes ≥15 cm (most important between 15 and 25 cm) (Fig. 4).

3.4. *Pagellus erythrinus*

The parameters and the statistics for the best overall selection model of *P. erythrinus* appear in Table 3. The model generally fitted the data well, although large 95% CI were obtained for the 40D escape and landing probability as a result of the very low number of individuals in these cases (Fig. 5).

The gear selection parameter of *P. erythrinus* was higher for the 50D codend, although overlap of the 95% CI was obvious between the 40D and 40S and between the 40S and 50D (Table 3). A significantly higher escape probability was detected for the 40S and 50D compared to the 40D at lengths >10 cm (mainly between 10 and 17 cm) (Fig. 6). The escape probability of the 50D codend compared to 40S was significantly higher at lengths between 13 and 16 cm TL (Fig. 6), associated with the higher SR_{gear} of the former codend (Table 3).

The discard probability of *P. erythrinus* showed higher values for the 40D codend (Fig. 5). Significantly higher values for the two diamond codends compared to the 40S were predicted for sizes ≤5 cm (Fig. 6). Comparison between the 40D and 50D revealed statistically significant higher discard probability for the sizes 10 – 11 cm TL for the former codend (Fig. 6). Some of the discard indicators of the 50D were lower than those of the other two codends, however, overlap in their 95% CI was obvious in all cases among the three codends (Table 2).

The landing probability of *P. erythrinus* revealed similar $L50_{land}$ for the three codends with overlap of their 95% CI (Table 3). Landing

Table 3
Selectivity parameters for *Pagellus erythrinus* and *Lophius budegassa* 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) or 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; DOF: degrees of freedom; AIC: Akaike criterion).

Species		Codend		
		40D	40S	50D
Pagellus erythrinus	**Model Parameter**	**Model** G:G: Richard FF: Logit	G: Gompertz F: Logit	G: Richards F: Gompertz
	$L50_{gear}$	9.72 (0.10–10.75)	11.02 (10.38–12.79)	13.40 (11.71–13.94)
	SR_{gear}	2.69 (0.10–7.66)	2.39 (1.40–2.73)	3.43 (2.00–6.92)
	$1/\delta_{gear}$	0.10 (0.10–10.00)		0.29 (0.10–10.00)
	$L50_{fisher}$	12.07 (11.48–13.31)	12.81 (0.10–13.34)	12.62 (11.66–13.13)
	SR_{fisher}	1.86 (1.31–2.68)	1.47 (0.88–6.15)	1.04 (0.10–1.55)
	$L50_{land}$	12.08 (11.49–13.31)	13.08 (12.41–13.45)	13.78 (12.80–14.21)
	SR_{land}	1.74 (1.31–2.68)	1.54 (0.97–2.06)	2.09 (1.59–2.63)
	p-value	1.0000	0.2350	0.9957
	Deviance	17.04	46.09	18.32
	DOF	47	40	37
	AIC	695.58	1048.59	499.78
Lophius budegassa	**Model Parameter**	**Model** G: Probit F: Gompertz	G: Probit F: Gompertz	G: Logit F: Logit
	$L50_{gear}$	4.71 (0.10–6.57)	4.43 (0.10–11.97)	5.27 (0.10–7.98)
	SR_{gear}	3.53 (0.10–4.69)	5.88 (0.10–9.59)	3.06 (0.10–3.40)
	$L50_{fisher}$	17.06 (15.97–19.49)	22.25 (19.75–24.00)	22.10 (19.93–24.55)
	SR_{fisher}	2.56 (1.22–3.49)	2.20 (0.10–3.94)	4.31 (2.18–6.51)
	$L50_{land}$	17.06 (15.97–19.49)	22.25 (19.76–24.00)	22.10 (19.93–24.55)
	SR_{land}	2.56 (1.22–3.49)	2.20 (0.10–3.93)	4.30 (2.18–6.51)
	p-value	1.0000	1.0000	1.0000
	Deviance	6.69	3.27	19.68
	DOF	68	60	66
	AIC	95.48	28.89	114.63

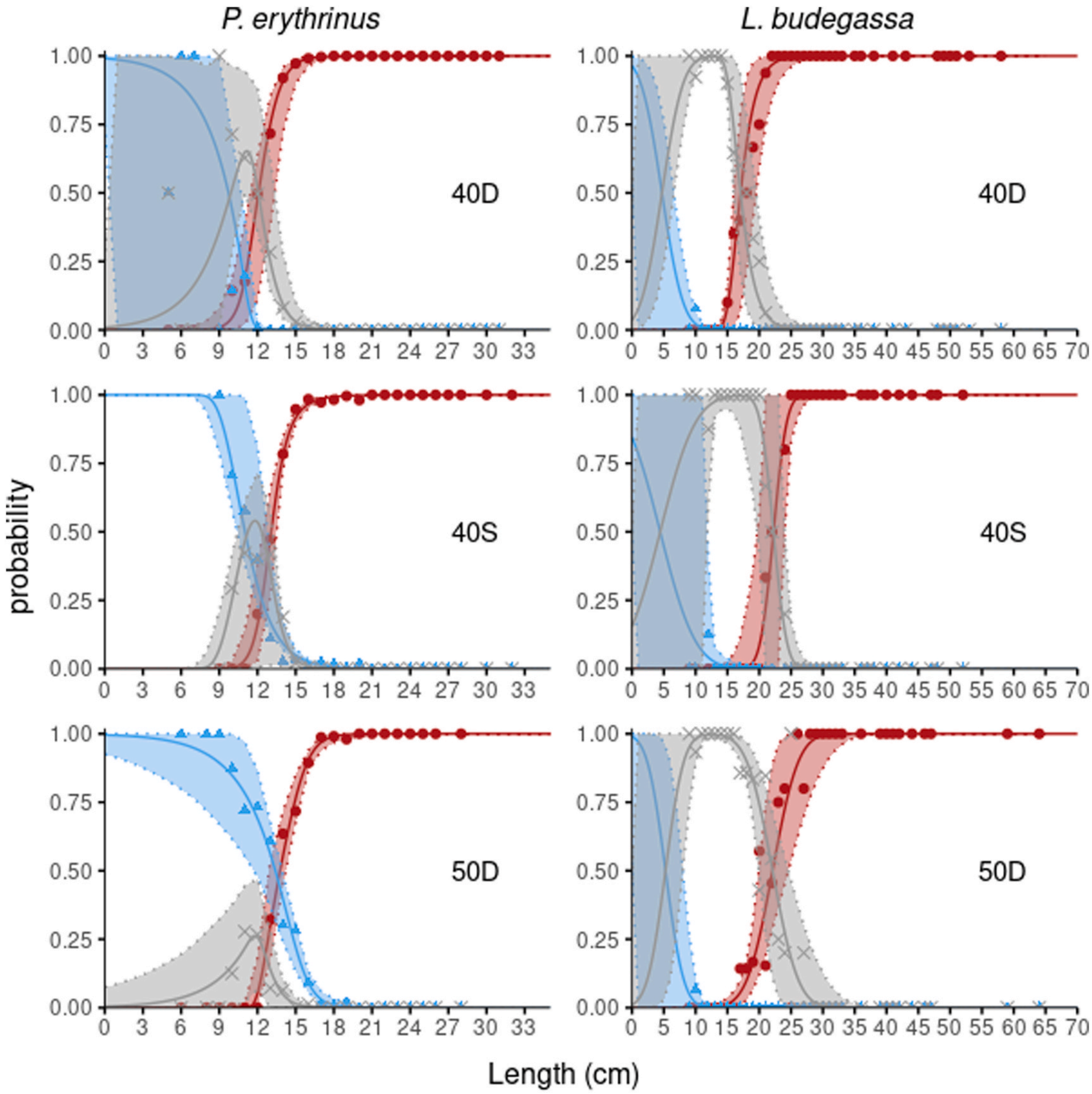

Fig. 5. Size-selection curves for *Pagellus erythrinus* and *Lophius budegassa* when using 40 mm diamond mesh (40D), 40 mm square mesh (40S) and 50 mm diamond mesh (50D) in the trawl codend. Blue curves and triangles: gear escape probability (p_{esc}) and associated experimental ratios; grey curves and crosses: discard probability (p_{disc}) and associated experimental ratios; red curves and dots: landing probability (p_{land}) and associated experimental ratios. Coloured areas around the curves: Efron percentile 95% confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

probability increased (>0.15) at sizes >10 cm for the 40D and >12 cm for the 50D and 40S (Fig. 5). Fisher landing probability did not differ between the 40D and 40S, whereas significant lower values were detected for the 50D than 40D or the 50D than 40S at lengths 14–17 cm and 14–16 cm, respectively (Fig. 6).

3.5. *Lophius budegassa*

The parameters and statistics for the best overall selection model of *L. budegassa* appear in Table 3. The model generally fitted the data well, although the very low number of individuals in the small sizes (<10 cm) resulted in wide 95% CI for the escape curve and the left side of the bell-shaped discard curve (Fig. 5).

The gear selection parameter of *L. budegassa* was very low and similar among the three codends (Table 3). The escape probability decreased notably (<0.3) in all cases at lengths ≥7 cm (Fig. 5) with no significant differences among the three codends (Fig. 7).

The discard probability of *L. budegassa* showed very high values (from 0.5 to 1.0 for sizes between 5 and 22 cm) for all codends TL (Fig. 5), indicating that a large part of the total amount of *L. budegassa* entering the tested gears is discarded. A significantly lower discard probability was predicted for the 40D compared to 40S and 50D codends for the sizes 17–18 cm and 17–23 cm, respectively (Fig. 7). No significant differences were detected between the 40S and 50D (Fig. 7). Similar indicators were obvious among the three codends with overlap in their 95% CI (Table 2).

Landing probability of *L. budegassa* increased (>0.15) at sizes >15 cm for the 40D and >18 cm for the 50D and 40S, respectively (Fig. 5). $L50_{land}$ for the 40D presented a significantly lower value compared to the other codends. A significantly higher landing probability for the 40D than the 40S or 50D was found at lengths from 16 to 19 cm and 17 to 23 cm, respectively (Fig. 7). Similar was the value of $L50_{land}$ for the 40S and 50D (Table 3).

4. Discussion

The overall size-selection during trawl fishing, based on the two sequential selection processes, by the codend in the sea and by the fisher onboard the fishing vessel, was modelled in the present work for four commercially important species. The model, introduced by Mytilineou

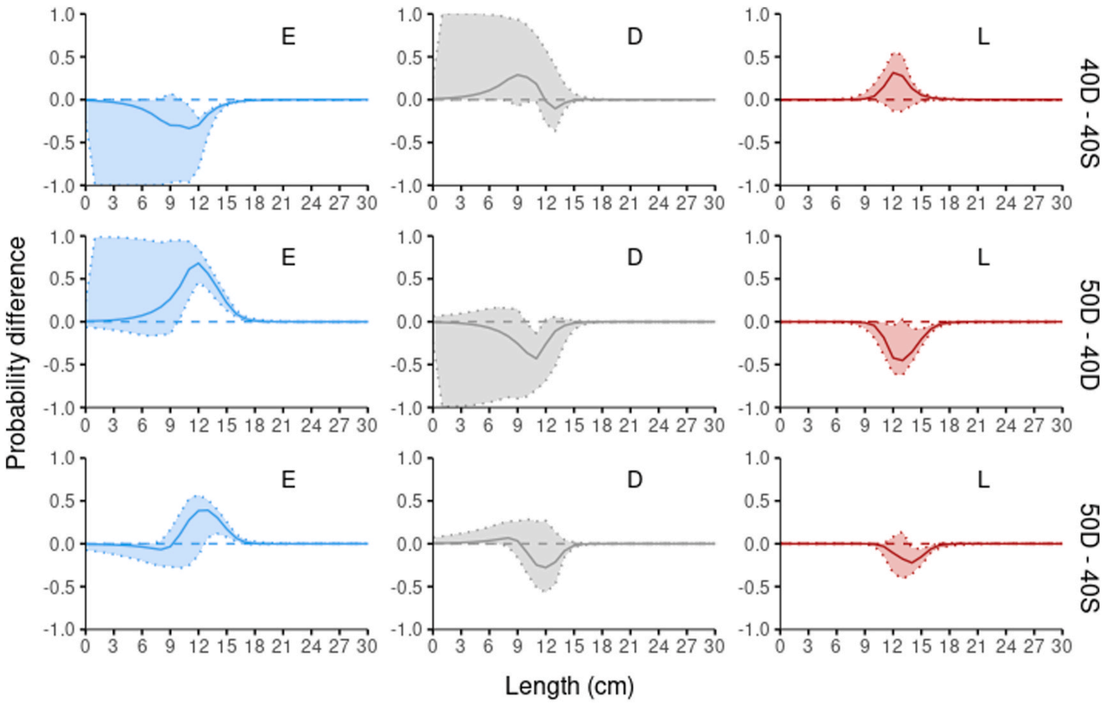

Fig. 6. Difference in the *Pagellus erythrinus* size-dependent escape (E), discard (D) and landing probability (L) (in blue, grey and red colour, respectively) between 40D - 40S, 50D - 40D and 50D – 40S codends. 40D, 40S, 50D: trawl codend with 40 mm diamond mesh, 40 mm square mesh, 50 mm diamond mesh, respectively; coloured areas around lines: 95% Efron percentile confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

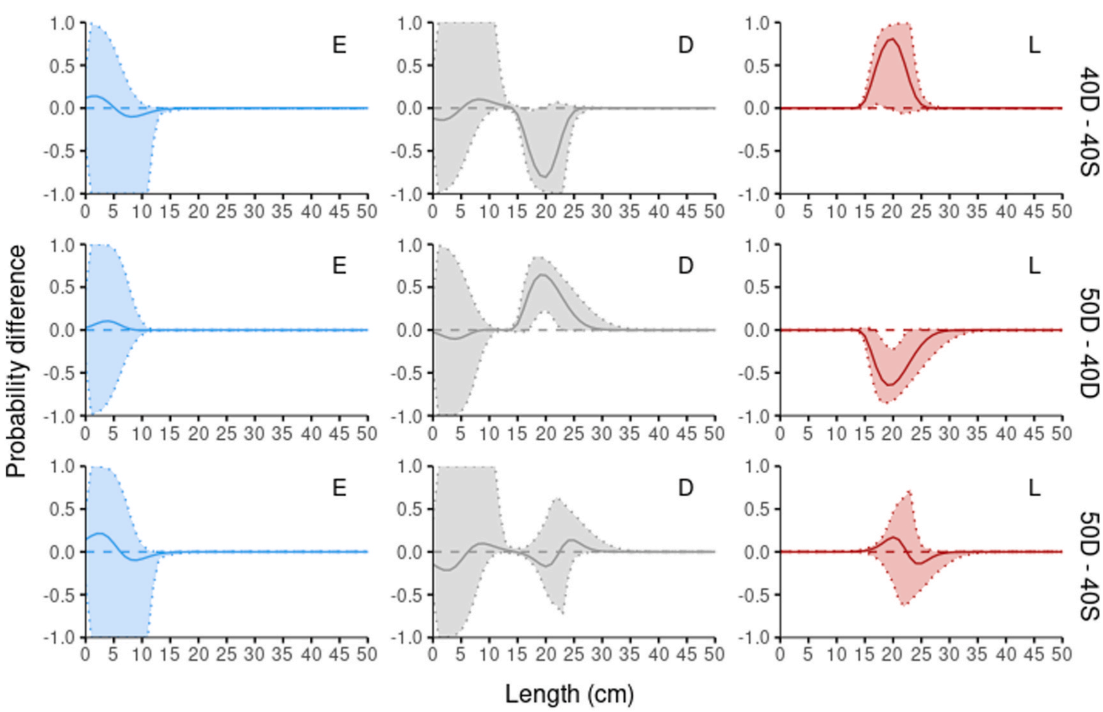

Fig. 7. Difference in the *Lophius budegassa* size-dependent escape (E), discard (D) and landing probability (L) (in blue, grey and red colour, respectively) between 40D - 40S, 50D - 40D and 50D – 40S codends. 40D, 40S, 50D: trawl codend with 40 mm diamond mesh, 40 mm square mesh, 50 mm diamond mesh, respectively; coloured areas around lines: 95% Efron percentile confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

et al. (2018), fitted the data well in all cases in this study and simultaneously predicted the escape, discard, and landing probability of the four species using only the data from a selectivity experiment. In the past, these estimates were usually obtained by separate studies. The results also showed that the model can be applied to more species than those examined by Mytilineou et al. (2018). Nevertheless, it should be mentioned that 95% CI may be wide in case of poor data.

The results for *M. barbatus* showed that the 40S codend was more selective than the two diamond codends. $L50_{gear}$ for the 40D was significantly lower than the MCRS of 11 cm TL, showing the inadequacy of this codend for the sustainability of the species. $L50_{gear}$ for the 40S was slightly higher than MCRS and similar to the length at first maturity of *M. barbatus* ($L50_{mat}$: 12.9 cm TL; Tsikliras and Stergiou, 2013). MCRS was included between the 95% CI of $L50_{gear}$ for the 50D. However, higher SR_{gear} was estimated for 50D compared to 40S, resulting in i) the retention of undersized individuals (<11 cm) that will be discarded or landed (in the case of 40S they escape) and ii) the escapement of individuals (≥17 cm TL) much larger than the MCRS and the $L50_{mat}$. The fisher behaviour for this species was characterised by the selection of individuals less than the MCRS as landings, depending on the availability of these individuals in the catch. As a result, the landing probability was higher for both the 40D and 50D than the 40S in the undersized individuals of *M. barbatus* and the parameter $L50_{land}$ of the diamond codends was significantly lower than that of the 40S, although for the 50D it was close to the MCRS of the species. $L50_{land}$ for the 40S was similar to $L50_{mat}$, indicating that the fisher selection pattern is guided towards more sustainable behaviour for the stock and higher compliance with the rules when the 40S is in use. The significantly lower landing probability between the 40S and 40D or 50D indicated economic losses at sizes slightly above the MCRS. In contrast, higher economic losses are expected using the 50D, as larger and more economically valuable individuals escape through this codend. Moreover, the discard probability was very low in all cases, except for sizes close to the MCRS, being higher for both diamond codends. Based on the above results, it could be suggested that among the tested codends, the 40S is the most adequate gear for *M. barbatus* in terms of the sustainability of the stock, with i) a gear selection close to $L50_{mat}$, ii) lawful catch with negligible discards and iii) fisher selection pattern associated with more compliance and the least economic losses in the short term. Furthermore, the 40S codend is also more promising regarding the Commission Delegated Regulation (Eu) 2017/86 that permits discards up to 6% of the total annual landings of *M. barbatus*.

The model for *M. surmuletus* showed that the 40S codend was more selective than the two diamond codends, as in the case of the congeneric species *M. barbatus*. $L50_{gear}$ for the 40D was significantly lower than the MCRS of 11 cm TL indicating that this codend is inappropriate for this species. For the 40S, $L50_{gear}$ was a little higher than MCRS, but lower than the length at first maturity of *M. surmuletus* ($L50_{mat}$: 15.5 cm TL; Tsikliras and Stergiou, 2013). The MCRS was included between the 95% CI of the gear selection parameter for the 50D codend, but it was also lower than $L50_{mat}$. Moreover, the higher SR_{gear} of this codend compared to the 40S had as a result the retention of more undersized individuals (<11 cm) that will be discarded or landed. The fisher behaviour for this species was also characterised by the selection of individuals less than the MCRS as landings, depending on the availability of these individuals in the catch. Therefore, the landing probability for the undersized catch of *M. surmuletus* was higher when the 40D was in use. The $L50_{land}$ of the 50D codend had a similar value to MCRS, but lower than the $L50_{mat}$ of the species. Although still low, $L50_{land}$ of the 40S was slightly closer to $L50_{mat}$ indicating that, fisher selection pattern would be directed to a more sustainable practice for the stock in this case. Furthermore, less economic losses for the fisher are expected with the 40S compared to the 50D, because the latter permit the escapement of much larger than the MCRS and the $L50_{mat}$ individuals that are marketable and of high economic value. Furthermore, in contrast to the 40S, the diamond codends presented a higher discard probability in the sizes of juveniles. All the above let us suggest that among the three codends, although none achieved $L50_{mat}$, the 40S is the most effective for *M. surmuletus* sustainability, with a lawful catch and a fisher selection pattern associated with better compliance to rules, no discards and thus less time spent by the crew in sorting, and the lowest possible economic losses. Sola and Maynou (2018) tested the use of a panel with 90° turned meshes in the extension part of the trawl, however, with economic losses for the fishers.

For *P. erythrinus,* the 50D codend showed the highest $L50_{gear}$, which however cannot be considered significantly different from that of the 40S, because of the overlap of their 95% CI. The 40D presented the worst $L50_{gear}$ without significant difference from 40S. Thus, none of the codends displayed a gear selection close to the MCRS of the species (15 cm TL), which is close to the length at first maturity of the species ($L50_{mat}$: 16.4 cm TL; Tsikliras and Stergiou, 2013). Furthermore, the discard likelihood did not show important differences among the examined codends. Fisher selection behaviour was also similar for all tested codends and was always below the MCRS and the length at first maturity. However, because of a higher SR_{gear}, the 50D codend presented a higher escape probability around the MCRS and the length at first maturity of the species, which might indicate a more promising pattern (although not sufficiently successful) than the 40D and 40S. This means that the use of the 50D codend may produce some economic losses in the short term. These losses will be higher in the case of a potential increase of the codend mesh size to improve gear selection and reach the MCRS. Such an improvement in gear selection seems difficult unless an innovative modification of the gear achieves this goal. The use of the 50D or 40S and the protection of the species nursery grounds may be an alternative measure for the sustainability of the species stocks and the mitigation of discards, as proposed for other species (Khoukh and Maynou, 2018; Russo et al., 2019; Mytilineou et al., 2020).

L. budegassa gear selection was very negligible in all cases. Almost all individuals were retained and the greatest part of the catch with sizes <22 cm has been predicted as discards. Even the fish sorted as landings by the fisher were in their majority of much smaller length than the length at first maturity of the species ($L50_{mat}$: 48–59 cm TL; Duarte et al., 2001; Colmenero et al., 2013). Therefore, none of the three codends is adequate for this species in terms of juvenile protection and discards. This fact is probably related to the body features of this species characterised by a large head and a benthic and relatively inactive behaviour inside the trawl codend (Mytilineou, unpublished data) that reduces its escape probability. Gear selectivity needs considerable improvement for this species. However, considering the difference between the gear selection and the $L50_{mat}$, this seems impossible without a huge increase of the codend mesh size (probably resulting in the loss of other commercially important catch), another innovative change in the gear design (as proposed for other species in ICES WKING, 2020) or the protection of the species nursery grounds as proposed for other species (Khoukh and Maynou, 2018; Russo et al., 2019; Mytilineou et al., 2020).

In summary, the 40D mesh in the trawl codend can be considered a mesh of low selectivity, unsafe and inappropriate for the protection of juveniles, the mitigation of discards and the sustainability of the stocks as also suggested by many researchers. Even in the case of economic losses from the change of the 40D to another codend, the losses are mainly associated with undersized, below the MCRS or the length at first maturity, catch. The 40S codend was more suitable in terms of stock sustainability and with less economic losses for the fisher than the 50D for the two *Mullus* species (although not reaching the MCRS for *M. surmuletus*). No one of the 40S or 50D codends was suitable for *P. erythrinus,* although 50D showed a little higher escape probability at sizes around MCRS, accompanied however by more economic losses for the fisher. All the tested codends seemed harmful for *L. budegassa*.

The results of L_{50gear} for the studied species published in the literature are presented in Table 4. Comparisons of L_{50gear} among the various researchers are not easy, because several factors such as the net material, the nominal or actual mesh size, the number of mesh sizes in the codend circumference, the knotted or knotless design, the catch size and shape and other factors may affect the codend selectivity (e.g. Herrmann, 2005; Sala and Lucchetti, 2010). Nevertheless, some of the published L_{50gear} are in agreement with our results, especially when the net characteristics seemed similar (Table 4, e.g. Sala et al., 2015: for *M. barbatus*; Ordines et al., 2006: for *M. surmuletus* in 40S codend; Ateş et al., 2010:

Table 4

L_{50gear} (length at which 50% of the individuals are retained by the trawl codend) and $L_{50fisher/discard}$ (length at which 50% of the retained in the codend individuals are discarded by the fisher) for *M. barbatus, M. surmulatus, P. erythrinus* and *L. budegassa* from the Mediterranean Sea published in the literature. The results of the present work are also shown. Mesh characteristics are also given.

Species	Mesh	L_{50gear} (cm TL)	$L_{50fisher/discard}$ (cm TL)	Reference	Area
M. barbatus	40D600_PE[a]	10.60		Tosunoğlu et al. (2003)	E. Aegean Sea
	40D600_PE	10.1		Özbilgin and Tosunoğlu (2003)	E. Aegean Sea
	40D220_PE	9.14		Tokaç et al. (2014)	E. Aegean Sea
	40T90220_PE	12.41			
	44D200_PE	11.35			
	44T200_PE	14.62			
	50D176_PE	14.66			
	44D200_PA	10.7		Ateş et al. (2010)	Antalya Bay (Levantine Sea)
	40S100_PE	14.2			
	50D200_PE	15.2		Aydin et al. (2011)	E. Aegean Sea
	40S100_PE	14.4			
	44D320_PA	8.58		Sala et al. (2015)	Tyrrhenian Sea
	44S160_PA	13.20			
	54D256_PA	11.63			
	54S128_PA	17.28			
	44D400_PE_handmade	7.1		Özbilgin et al. (2015)	Mersin Bay (Levantine Sea)
	44D300_PE_machine	8.4			
	50D265_PE_machine	12.1			
	40S150_PE_machine	14.1			
	44D300_PE	11.1		Dereli and Aydin (2016)	E. Aegean Sea
	50D264_PE	12.9			
	40T330_PE	13.6			
	40S165_PE	12.9			
	50D246_PE	9.81		Brčić et al. (2018)	Tyrrhenian Sea
	40D400_PA	9.34	8.71	Present work	S. Aegean Sea
	50D340_PA	10.83	9.41		
	40S200_PA	13.31	10.48		
	28D		10.1–11.1	Machias et al. (2004)	E. Ionian Sea
	40D/40S		6.2–7.4	Damalas et al. (2018)	Aegean Sea
M. surmuletus	40D_PE	4.5		Ordines et al. (2006)	Balearic Isl.
	40S_PE	12.2			
	40D400_PA	8.40	8.05	Present work	S. Aegean Sea
	50D340_PA	10.84	9.08		
	40S200_PA	12.04	–		
P. erythrinus	40D600_PE	10.5		Özbilgin and Tosunoğlu (2003)	E. Aegean Sea
	40D600_PE	10.80		Tosunoğlu et al. (2003)	E. Aegean Sea
	40D_PE	–		Ordines et al. (2006)	Balearic Isl.
	40S_PE	10.4			
	44D200_PA	11.8		Ateş et al. (2010)	Antalya Bay (Levantine Sea)
	40S100_PE	11.0			
	50D200_PE	15.0		Aydin et al. (2011)	E. Aegean Sea
	40S100_PE	13.1			
	44D400_PE_handmade	8.3		Özbilgin et al. (2015)	Mersin Bay (Levantine Sea)
	44D300_PE_machine	11.7			
	50D265_PE_machine	15.1			
	40S150_PE_machine	13.0			
	40D220_PE	8.73		Tokaç et al. (2014)	E. Aegean Sea
	40T90220_PE	10.23			
	44D200_PE	11.10			
	44T200_PE	12.76			
	50D176_PE	14.66			
	40D400_PA	9.72	12.07	Present work	S. Aegean Sea
	50D340_PA	13.40	12.62		
	40S200_PA	11.02	12.81		
	28D		12.2–13.2	Machias et al. (2004)	E. Ionian Sea
	40D		~12.0	Damalas and Vasilopoulou (2013)	Aegean Sea
L. budegassa	40D400_PA	4.71	17.06	Present work	S. Aegean Sea
	50D340_PA	5.27	22.10		
	40S200_PA	4.43	22.25		
	40D		14.9	Damalas et al. (2018)	Aegean Sea
	40D/40S		10.2		

[a] Mesh description: i) mesh size in mm, ii) mesh configuration (D: diamond, S: square, T: 90° turned mesh), iii) number of meshes in codend circumference, iv) twine material (PA: polyamid, PE: polyethylen).

for *P. erythrinus* in 40S codend). No published work on the gear selection of *L. budegassa* is known. The study of Tosunoğlu et al. (2008) on the 50D codend selection for the congeneric species *Lophius piscatorius* revealed no escapees and only retained individuals, results that are similar to the current study. Furthermore, based on the results of Table 4, it is worth mentioning that comparing the codends with similar meshes but with different circumference for the same species, in most cases, the lower the number of meshes in the codend circumference the higher the L_{50gear}. Moreover, it is clear that in most of cases, L_{50gear} for the 40S codend is higher than that of the 40D and 50D for *Mullus* species (Table 4). In contrast, in most cases, $L50_{gear}$ of *P. erythrinus* for the 50D was higher than that of the 40S and 40D, a fact probably associated with the body shape of this species, being noticeably deep and compressed; the widthwise stretching of the 50D meshes seems to benefit the escapement of this species. However, the MCRS of *P. erythrinus* was achieved only when the 50D was combined with a low number of meshes in the circumference (Table 4); lower than that used in commercial fishery.

Considering the results for $L_{50fisher/discard}$, derived from the applied model and selectivity data with those in the literature derived from observers onboard fishing vessels, it is worth noting that these were quite comparable in the case of *M. barbatus* and *P. erythrinus* (Table 4). The lower values found by Damalas et al. (2018) for *M. barbatus* and *L. budegassa* and Machias et al. (2004) for *M. surmuletus* may indicate a lower availability of small individuals in the catch and an increase in the fisher selection behaviour nowadays, probably because of the improved selectivity of the trawl codend according to the EC Regulation 1967/2006, implemented years later than 2006. It should also be mentioned that the hauls conducted in the present study for *L. budegassa* may not be spatially and temporally the most appropriate, a fact that may have affected the population structure of the species compared to that from the commercial fishery.

The model applied in this work was proved again to be a useful, cost-efficient approach in collecting information for fisheries management, as it simultaneously predicts important information on escapees, discards and fisher behaviour based on selectivity data. Moreover, discards and fisher behaviour related predictions, based on one vessel and one period data, were generally in accordance with those in the literature estimated from fleet-based data, which supports further the applicability of the model. Concerning the codend mesh, it could be suggested that the 40S codend, although not so adequate in all cases, is the most sustainable compared to the 50D for the Mediterranean trawl multispecies fishery. This information is useful in fisheries management since the use of the 50D is an alternative of the 40S according to the Council Regulation (EC) No 1967/2006. Nevertheless, within the concept of the ecosystem approach to fishery management, it seems that more changes should be investigated to improve the selectivity of the trawl codend with innovative gears (Brčić et al., 2015) or measures (Santiago et al., 2015) along with the protection of nursery grounds, particularly for species for which selectivity improvement cannot be achieved without important reduction of other commercial catch and consequently fisher income. More similar studies should be conducted in the future for other species since the trawl fishery in the Mediterranean is a multi-species fishery.

5. Conclusions

The model applied in this work, representing the overall selectivity on a population entering the trawl codend, is a cost-effective approach to collect information on the escapees, discards and landings of *M. barbatus, M. surmuletus, P. erythrinus* and *L. budegassa*. The 40 mm diamond mesh codend was always inappropriate for the stocks. The 40 mm square mesh codend was the most effective for the sustainability of both *Mullus* species. None of the codends was adequate for *P. erythrinus* and *L. budegassa*. The 50 mm diamond codend does not meet the requirements of the current legislation for the Mediterranean bottom trawl in terms of better selectivity compared to the 40 mm square mesh codend.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2021.105653.

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