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Comparative Analysis of Various Trawl Codend Selectivity for Red Mullet (*Mullus barbatus*) and Whiting (*Merlangius merlangus*) in the Black Sea

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Abstract

The aim of this study was to estimate the selectivity of 40 mm (*40D*) and 44 mm (*44D*) diamond mesh size, 40 mm square (*40S*), and turned (*40T*) mesh codend for red mullet (*Mullus barbatus*) and whiting (*Merlangius merlangus*). Samples were collected from two locations in the western Black Sea during 21-28 July 2020 using covered codend method was used in experiment. For red mullet, the mean fifty-percent retention length (L_{50}) values for *40D*, *40S*, *40T* and *44D* were estimated at 8.55 (8.02–8.93) cm, 12.04 (11.03–12.80) cm, 11.46 (10.11–11.99) and 13.23 (12.69–13.71) cm respectively. L_{50} values of *40D*, *40S*, *40T* and *44D* were determined as 10.06 (8.59–12.58) cm, 15.61 (14.74–16.24) cm, 15.45 (14.48–15.54) cm, 13.56 (12.63–14.11) cm for whiting, respectively. The estimated L_{50} of the commercially used *40D* codend was lower than the Minimum Conservation Reference Size (*MCRS*) for red mullet and whiting (13 cm). All tested experimental codends improved the size selectivity of the studied species compared with the legally allowed minimum mesh size (40 mm). In addition, the discard rate for red mullet using the 40D codend, which is commonly employed in the Black Sea, was found to be 97.90%. The implementation of 40S codends could reduce this rate to approximately 84.57%. Similarly, for whiting, the discard rate decreased from approximately 74.09% to 59.03%, depending on the tested experimental codends. The size selectivity and exploitation pattern of codends for red mullet and whiting could be improved by simply changing to square (*40S*) or turning (*40T*) meshes, based on *MCRS*. Also, the present study provides the scientific foundation for the regulation concerning the increase of the codend mesh size of diamond 44 mm in trawl fishing in the Black Sea, which is scheduled for implementation in 2028.

Introduction

Selectivity refers to the ability of fishing gear to catch only the target species and capture specific sizes or species of fish while avoiding non-target species and undersized individuals (Millar and Fryer, 1999; Wileman et al.,1996). Improving selectivity has been a strong priority in terms of achieving the management sustainably, the health of marine ecosystems and a critical factor that determines bottom trawling efficiency (Alverson and Hughes, 1996; Wileman et al., 1996; Alverson, 1997; Crowder and Murawski, 1998; Millar and Fryer, 1999; Catchpole and Gray, 2010; Kazemi, 2014). Several strategies have been developed to improve trawl selectivity, including modifications to the fishing gear, changes to fishing practices, and codend modifications. The codend is part of the trawl net where fish are retained, and it plays a crucial role in the size and species composition of the catch. Codend mesh size limitation for bottom trawls, Minimum Conservation Reference Size *(MCRS)* regulation (13 cm total length for both species), and a seasonal summer ban on all industrial fishing are the national measures to help rebuild the exploited stocks in Turkish waters (Anonymous, 2024). Inherently, selectivity-based improvements in the fishing process can help decrease the current fishing pressure by releasing juvenile and unwanted sizes from codend.

In the Black Sea, fishing activities are restricted to depths shallower than 150–200 meters due to the anoxic conditions of the waters. The maximum depth reached by demersal trawling and bottom-set gillnets in the Black Sea basin is around 100–120 m and most frequently between 80–100 m (UN, 2023). Whiting (*Merlangius merlangus*) and red mullet (*Mullus barbatus*) are important commercial fish species in the Black Sea (Turkstat, 2025). These are fished commercially by the industrial and artisanal fisheries with various fishing gears (bottom trawls, gillnets, deep water cast nets) (Yildiz and Karakulak, 2016; Yildiz et al., 2021). Based on water temperature variations, they migrate for spawning and feeding throughout the year (Whitehead et al., 1986). These traits enable them to be targeted for fishing over an extended portion of the year (Yildiz, 2016; Yildiz and Karakulak, 2019). Whiting in the Black Sea undertakes temperature-driven vertical migrations, moving into warmer surface waters (15–30 m; 5–16°C) each spring to feed and spawn, then retreating to deeper layers (80–120 m) during hot summers (>20°C) and cold winters (Aydın et al., 2008; Bilgin et al., 2012; Kasapoglu, 2018). Likewise, red mullet migrates into shallow coastal zones (0–20 m) in spring, spawns most intensely during July–August at 18–25°C, and descends to 50–100 m in autumn for overwintering (Genç, 2000; Mikeladze et al., 2023; Kasapoglu, 2018). In Greek waters off Crete, red mullet undertakes a seasonal shelf-scale movement—remaining in shallow (<50 m) warmer waters in winter, then shifting to mid-shelf depths (60–100 m) each spring in close association with spawning (Machias et al., 1998); in the Adriatic Sea, whiting shows a strong preference for ~ 45 m depth and ~ 15.4°C seafloor temperatures during the productive spring–summer period (Asciutto et al., 2024)

According to Turkish National Fisheries Statistics (Turkstat, 2025), whiting and red mullet dominate the main demersal landing in the south-western Black Sea. The multi-species industrial fishery (targeting mainly whiting, turbot, and red mullet) consists of 197 otter bottom trawlers in the western Black Sea. Over the past 20 years, the national yearly landings of whiting and red mullet have ranged from 6,813.9 to 13,558 tons and from 1,066.7 to 2,825 tons, respectively (TurkStat, 2025). In 2024, 13.61% of the red mullet and 54.37% of the whiting caught within the country were harvested from the western Black Sea. According to the General Fisheries Commission for the Mediterranean (*GFCM)* assessment, red mullet have been overfished, therefore it is recommended to reduce fishing mortality (FAO, 2023). Enhancing gear selectivity is a key strategy to achieve this, as it can reduce bycatch and promote sustainable fishing practices (Broadhurst, 2000; Catchpole and Gray, 2010; Krag et al., 2025).

In the Black Sea, many commercially important demersal species are targeted by bottom trawling. However, studies on gear selectivity in this region remain limited. This highlights the need for further research to better understand the implications of selectivity in fisheries management and its role in maintaining ecosystem balance. Although previous studies have investigated the selectivity of whiting and red mullet concerning various mesh sizes (ranging from 32 mm to 44 mm) and different mesh shapes (diamond, square, and T90) along the eastern and central regions of Turkey's Black Sea coast (Zengin et al., 1997; Zengin and Düzgüneş, 1999; Genç et al., 2002; Özdemir, 2006; Kaykac et al., 2018; Zengin et al., 2019), a notable gap remains in the literature, as no research has been conducted on the western Black Sea coast.

The current regulations in Türkiye allow usage of 40 and 44 mm diamond mesh in the Black Sea and Mediterranean Sea, respectively. The lack of information on the selectivity of trawl codends in the western Black Sea is a significant information gap that needs to be addressed. This information is crucial for developing effective management strategies that ensure the fisheries' sustainability and the marine ecosystem's protection. This study aims to address the knowledge gap concerning codend selectivity in demersal trawl gears operating in the Western Black Sea. Specifically, it investigates the selectivity of high-value species such as red mullet and whiting by testing various mesh configurations of 40 mm mesh, including diamond, square, and T90 meshes. One of the most important aspects of this study is to test a 44 mm diamond mesh codend configuration for fisheries in the Western Black Sea, with the aim of establishing a scientific basis for its adoption as an alternative to the currently used 40D mesh. The findings are expected to inform regulatory measures that will mandate this new standard across the Black Sea by 2028. Additionally, this study is the first to assess the size selection performance of 40 mm turned mesh codend from the trawl fisheries in the western Black Sea.

Material and Methods

Study Area, Trawl Rigging, and Data Collection

Samples were collected from two locations in the western Black Sea: Kefken (Kocaeli) (41° 9'7.53"N - 30°11'0.86"E) and Kıyıköy (Kırklareli) (41°42'9.95" N - 28°E) during 21-28 July 2020 (Figure 1). The fishing trials were conducted using the R/V Yunus S, a 32-meter vessel owned by the Faculty of Aquatic Sciences at

Istanbul University. The vessel was equipped with a 500 HP engine. The towing duration for all trials was limited to 30 minutes. The mean trawling depths varied between 5 and 22 meters, and the towing speeds ranged from 2.7 to 3.1 knots, with a mean speed of 2.9 knots. For each haul, the total catch weights from the cod-end and cover were recorded. The values were then standardized to kilograms per hour of haul duration.

A 900-mesh conventional bottom trawl was used in all experiments. Three different mesh configuration of 40 mm mesh size and increasing mesh size from 40 mm to 44 mm mesh size codends were tested:

1. 40 mm diamond mesh codend (40D)
2. 40 mm square mesh codend (40S) cut from a diamond mesh netting as in (Santucci et al., 2024).
3. 40 mm T90 codend obtained by turning the diamond mesh netting by 90°(40T) (Wienbeck et al., 2011).
4. 44 mm diamond mesh codend 44D

All codends were 5 meters in length and made of polyethylene knotted netting with a material specification of 210d/ 24 no. Tested codends where systematically exchanged so that all were subjected to the same fishing conditions and availability of fish populations. The codends were rigged at the end of the tunnel and had specific circumferences based on their mesh sizes (Figure 2). The *44D* codend had a circumference of 300 meshes (44 mm×300=13,200 mm). Similarly, the *40D* codend had a circumference of 330 meshes (40 mm×330=13,200 mm). According to Council Regulation No. 1967 ⁄ 2006 (E.C., 2006), the square-mesh codend's circumference should be equal to the rearmost part of the trawl body. Therefore, the *40S* codend had a circumference of 165 meshes (13,200 mm÷40 mm=330 meshes÷2=165 meshes). The *40T* codend, tested as a turned mesh, also had a circumference of 165 meshes (Table 1). To determine the mean mesh size of the codends, a total of 80 stretched mesh openings (four lines of 20 consecutive meshes in the towing direction) near to the aft were measured in wet conditions using OMEGA mesh gauge at 50 N (Fonteyne et al., 2007). Specifications of the codends and the cover are given in Table 1.

The selectivity data were collected using the covered codend method (Wileman et al., 1996). A cover with a length of 8 meters and 450 meshes on its circumference was used. The cover was made of knotless Polyamide netting with a diamond mesh size of 24 mm. It was supported by two hoops with a half-diameter of 1.6 meters, made of *PVC* material. The cover diameter was calculated by (Wileman et al., 1996). The hoops were attached to the cover at distances of 1.4 and 4 meters from the attachment point, which was at the end of the funnel. After lifting the experimental trawl, the catches were sorted by species on deck. The total body length (TL) of all measured individuals were rounded to the nearest 0.5 cm. Further information about the hauling process can be found in the Appendix section.

Analysis of Size Selection Data

The applied experimental design enabled analysis of the collected catch data as binominal data, where individuals either are retained by the codend cover or by the codend itself, and are used to estimate the size selection in the codend (i.e., length-dependent retention probability). The proportion of target species (red mullet and whiting) of length *l* retained in the codend is modelled and averaged over hauls with the function $r_{av}(l,\boldsymbol{v})$, where $\boldsymbol{v}$ is a vector representing two or more size selection parameters to be estimated (Herrmann, Sistiaga, Nielsen, & Larsen, 2012). This would provide information about the average consequences for the size selection process of applying

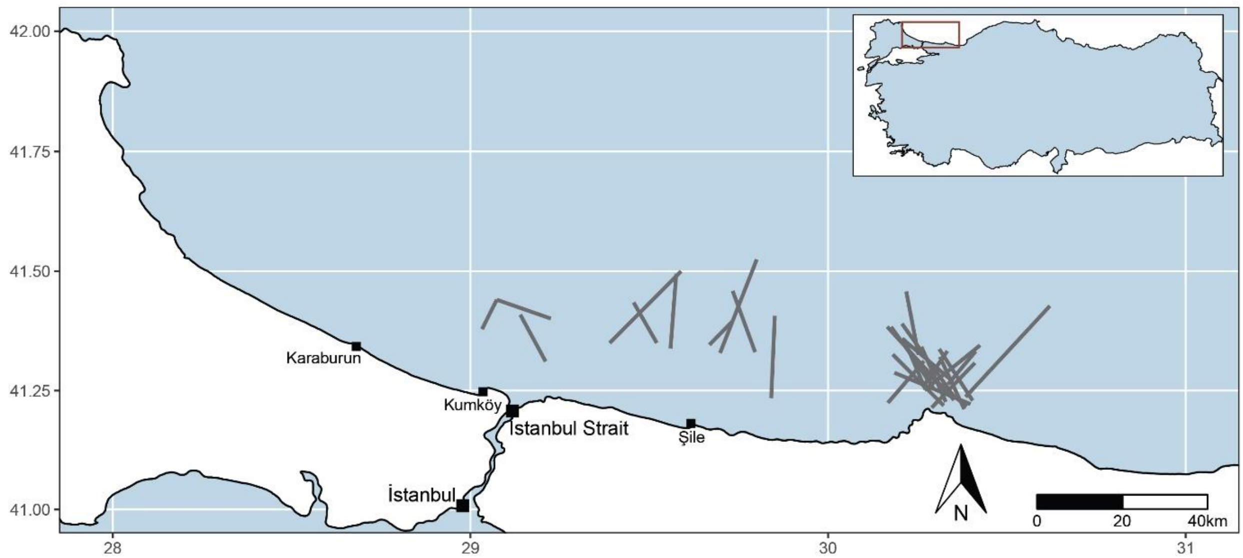

Figure 1. Map of the area where the sea trials were conducted.

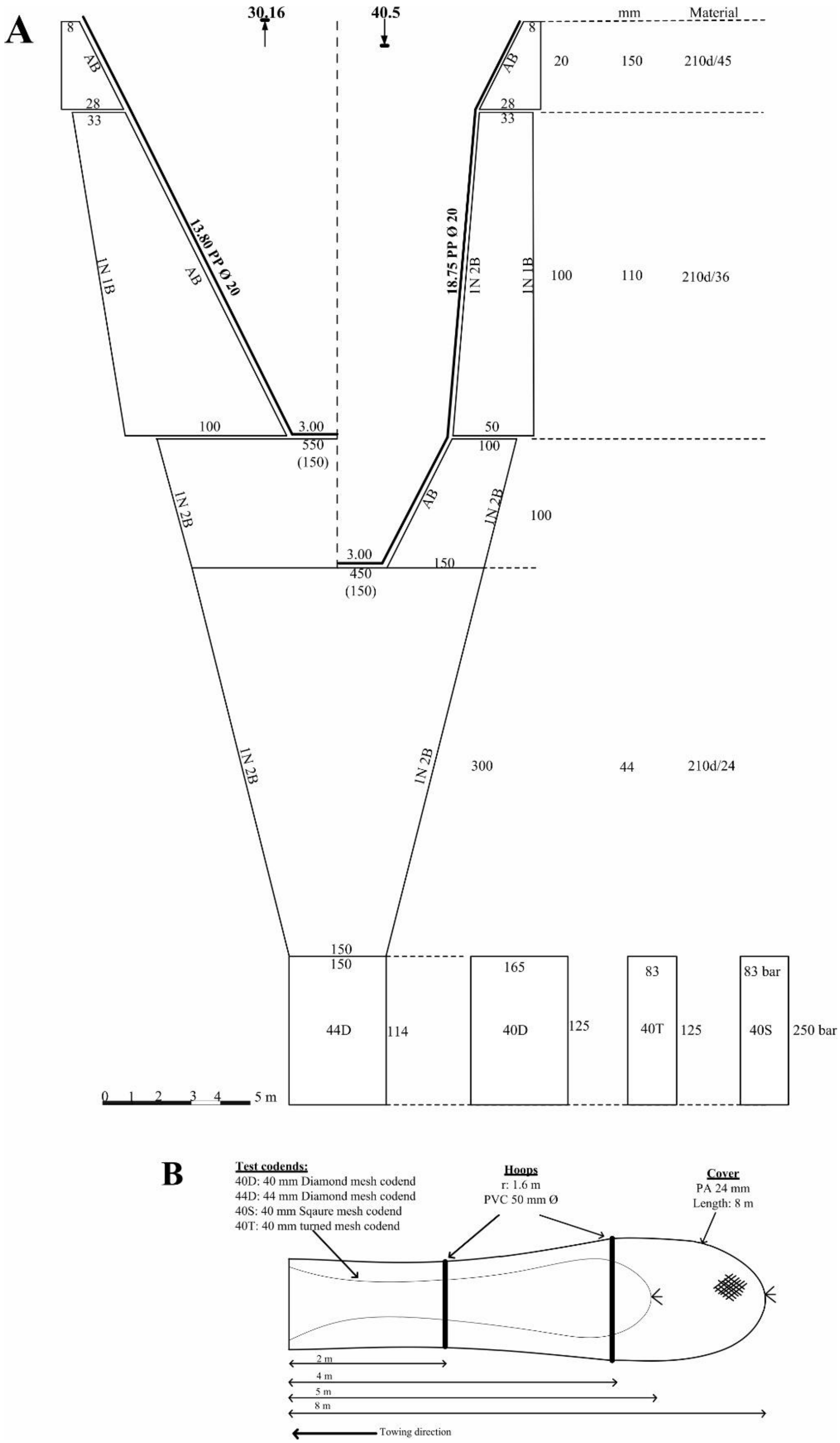

Figure 2. (A) Technical specification of the experimental trawl and, (B) schematic diagram of covered codend system used in experiments.

different codends in the fishery. Therefore, it was assumed that the size selective performance of a specific codend for all the individual hauls conducted within a trial was representative of how the codend would perform in a commercial fishery (Millar, 1993; Sistiaga, Herrmann, Grimaldo, & Larsen, 2010). Size selection was estimated by minimizing expression (1) with respect to parameters **v**, which is equivalent to maximizing the likelihood for the observed data in form of the length-dependent number of target species retained in the codend versus those escaping to the cover:

$$-\sum_{j=1}^{m}\sum_{l}\left\{\frac{nR_{jl}}{qR_j}\times\ln(r_{av}(l,v))+\frac{nE_{jl}}{qE_j}\times\ln(1.0-r_{av}(l,\boldsymbol{v}))\right\} \qquad (1)$$

where the outer summation is over the m hauls conducted with the specific codend in the specific sea trial and the inner over length classes *l*. *nRjl* and *nEjl* are the number of fish length measured in codend and cover in haul *j* belonging to length class *l*. *qRj* and *qEj* are the sampling factors for the fraction of the target species length measured in the codend and cover, respectively (Einarssonet al., 2021). Four basic selectivity models were tested to describe $r_{av}(l,\boldsymbol{v})$ for each codend: Logistic, Probit, Gompertz, and Richards (Eq. (2)), which assume that all individuals entering the codend are subjected to the same size selection process (Wileman et al., 1996).

Additional models tested include the CLogit model (Eq. (2)), where *C* represents the assumed length-independent contact probability with the codend meshes that provides fish with a length-dependent chance of escape (Bayse et al., 2016). *C* is a value from 0.0 to 1.0, and if *C*=1.0, all fish were able to have sufficient contact with the codend meshes. For the double logistic model (DLogit), C_1 represents the fraction of fish entering the codend that is subjected to one logistic size selection process with parameters $\boldsymbol{v}_1$ while the remaining fraction (1.0–C_1) that is subjected to an additional logistic size selection process with parameters $\boldsymbol{v}_2$ (Lipovetsky, 2010). Compared with DLogit, the triple logistic model (TLogit) introduces an additional size selection process, totaling three different processes C_1, C_2 and (1.0-C_1-C_2) probabilities of being the process that determine the codend size selection of the individual fish entering the codend (Frandsen et al., 2010). Finally, a quartic polynomial model (Poly4) was considered to estimate the codend size selection (Krag et al., 2015). For the Poly4 model, leaving out one or more of the parameters $v_0 \ldots v_4$ in Eq. (2) provided 31 additional models that were also considered as potential models to describe $r_{av}(l,v)$ (Cheng et al, 2019).

$$r_{av}(l,\boldsymbol{v})=\begin{cases} Logistic\ (l,\boldsymbol{v}) \\ Probit\ (l,\boldsymbol{v}) \\ Gompertz\ (l,\boldsymbol{v}) \\ Richards\ (l,\boldsymbol{v}) \\ CLogit(l,C,\boldsymbol{v})=1.0-C+C\times Logit(l,\boldsymbol{v}) \\ DLogit(l,C_1,\boldsymbol{v})=C_1\times Logit(l,\boldsymbol{v}_1)+(1.0-C_1)\times Logit(l,\boldsymbol{v}_2) \\ TLogit(l,C,\boldsymbol{v})=C_1\times Logit(l,v_1)+C_2\times Logit(l,v_2)+(1.0-C_1-C_2)\times Logit(l,v_3) \\ Ploy4(l,v)=\dfrac{exp\left(v_0+v_1\times\frac{l}{100}+v_2\times\frac{l^2}{100^2}+v_3\times\frac{l^3}{100^3}+v_4\times\frac{l^4}{100^4}\right)}{1.0+exp\left(v_0+v_1\times\frac{l}{100}+v_2\times\frac{l^2}{100^2}\times v_3\times\frac{l^3}{100^3}+v_4\times\frac{l^4}{100^4}\right)} \end{cases} \qquad (2)$$

In case of a poor fit statistic (P<0.05), the residuals were inspected to determine whether the poor result was due to structural problems when modelling the experimental data using the different selection curves or if it was due to the overdispersion of the data (Wileman et al., 1996). Akaike Information Criterion (AIC) values were used to determine the most parsimonious model (Akaike, 1974).

Once the specific size selection model was identified for a particular codend, bootstrapping was applied to estimate the confidence limits of the average size selection curve. The software tool SELNET (Herrmann et al., 2012) was used for size selection analysis, and a double-bootstrap method was implemented in this tool to obtain the confidence limits for the size selection curve and corresponding parameters. This bootstrapping approach was identical to the one described in Millar (1993) considering both within-haul and between-haul variations. To account for between-haul variations, an outer bootstrap resample with replacement from a group of hauls was included in the procedure. Within each resampled haul, the data for each length class were resampled in an inner bootstrap with replacement to account for within-haul variations. Each bootstrap resulted in a 'pooled' set of data, which was analysed using the identified selection model. Thus, each bootstrap run resulted in an average selection curve. For each analysed species, 1000 bootstrap repetitions were conducted to estimate the Efron's (1982) 95% confidence intervals (CIs) (Herrmann et al., 2012).

Table 1. Codend specifications used in the experimental fishing conducted in the western Black Sea

Section	40D	40S	40T	44D	Cover
Nominal mesh size (mm)	40	20 (bar lengths)	40	44	24
Measured mesh size (Mean±SE mm)	40.3±0.89	40.1±0.98	40.4±0.82	44.3±0.93	_
Netting material	PE (Knotted)	PE (Knotted)	PE (Knotted)	PE (Knotted)	PA (Knotless)
Circumference mesh no	330	165 (bar)	165	300	450
Stretches lengths (m)	5	5	5	5	8
Rigging ratio	1	0.5	0.5	1	–

Inferring the Differences in Size Selectivity Between Codends

To determine the differences in retention probabilities, the following generic delta curve ($\Delta r(l)$) was used:

$$\Delta r(l) = r_{test}(l) - r_{baseline}(l) \quad (3)$$

where on a case-by-case basis, $r_{test}(l)$ is the retention probability value of a specific codend with modified design, and $r_{baseline}(l)$ is the retention probability value of the baseline design in each pairwise comparison. Efron's 95% CIs for $\Delta r(l)$ were obtained based on the two bootstrap populations of the results (1000 bootstrap repetitions in each). As bootstrap resampling was random and independent for the two groups of results, it was valid to generate a new bootstrap population for the difference (3), based on the two generated bootstrap files (Herrmann et al., 2018):

$$\Delta r(l)_i = r_{test}(l)_i - r_{baseline}(l)_i \quad i \in [1 \ldots 1000], \quad (4)$$

where *i* is the bootstrap repetition index. Significant differences in the size selection of each length class between codends were obtained if the 95% CIs for the delta curves included the 0-axis for this length class.

Estimation of Fishing Efficiency Indicators

To investigate how applying the considered codends would affect the capture pattern in the fisheries, the value of three exploitation pattern indicators, *nP⁻*, *nP⁺* and *nDiscard*, were estimated. These indicators are often used in fishing gear size selectivity studies to supplement assessments solely based on selectivity curves (Sala et al., 2016; Santos et al., 2016; Brčić et al., 2018; Cheng et al., 2019; Kalogirou et al., 2019; Melli et al., 2020;). To estimate these efficiency indicators, the size selection curves predicted for each codend were first applied to the population of the studied species entering the fishing gear. This was obtained based on the data from all hauls for all codend designs during a specific season by summing the catches in codends and covers (Mytilineou et al, 2020). Uncertainties in populations were obtained by double bootstrapping, following the approach described in (Melli et al., 2020). Then, the percentage of individuals below (nP^-) and above (nP^+) the MCRS (13 cm) for each was calculated. Ideally, nP^- and nDiscard ratio should be low (close to 0), while nP^+ should be high (close to 100). The indicators were estimated for different codends using the equations provided below (Cerbule et al., 2024):

$$nP^- = 100 \times \frac{\sum_{l<MCRS}\{r_{codend}(l, \boldsymbol{v_{codend}}) \times nPop_l\}}{\sum_{l<MCRS}\{nPop_l\}}, \quad (5)$$

$$nP^+ = 100 \times \frac{\sum_{l>MCRS}\{r_{codend}(l, \boldsymbol{v_{codend}}) \times nPop_l\}}{\sum_{l>MCRS}\{nPop_l\}},$$

$$nDiscardRatio = 100 \times \frac{\sum_{l<MCRS}\{r_{codend}(l, \boldsymbol{v_{codend}}) \times nPop_l\}}{\sum_{l}\{r_{codend}(l, \boldsymbol{v_{codend}}) \times nPop_l\}}$$

All indicators (*nP⁻*, *nP⁺* and *nDiscard Ratio*) were estimated with uncertainties for each codend and population scenario, using a bootstrap set for $r_{codend}(l)$ and $nPop_l$. $nPop_l$ represents the total number of individuals entering the codend belonging to length class (Einarsson et al., 2021). Based on Herrmann et al. (2018), the bootstrap set to calculate for indicator values was obtained based on each bootstrap repetition result, applying $\mathrm{r_{codend}}(l, \mathbf{v_{codend}})$ and $\mathrm{nPop_l}$ simultaneously in Eq. (5). Finally, 95% confidence intervals were calculated for each indicator based on the resulting bootstrap sample. All analyses pertaining to these indicators were conducted using the software SELNET (Herrmann et al., 2012). All graphs were generated using RStudio (version 2025.05.0) with the 'ggplot2' (version 3.4.1) package (Wickham, 2016), within the framework of the data obtained from SELNET. Comparison of the indicators between the tested codends was based on the overlap of their *CIs*.

Results

Catch Composition

A total of 36 fish and macrozoobenthic species were obtained. Of these, 29 species are always discarded by local fishers, two species (*Mullus barbatus* and *Scophthalmus maximus*) are always retained, and five species (*Merlangius merlangus, Trachurus mediterraneus, Platichthys flesus, Chelidonichthys lucerna and Pegusa nasuta*) are marketable but small individuals are discarded. A total of 2 285 tons (240 824 individuals) of catch was obtained as a result of 31 trawl hauls). In terms of number, 73.22% of the catch was obtained from the cover and 26.78% from the tested codends, and in terms of weight, 68.89% was obtained from the cover and 31.11% from the tested codends.

Size Selectivity

The *AIC* values for the eight models (Logistic, Probit, Gompertz, Richards, CLogit, DLogit, TLogit, and Poly4) applied on the collected data by species are shown in Table 2. The lowest *AIC* value was selected to determine the most suitable model for the each codend.

The selectivity parameters for each species and codend, based on the best model, are given in Table 3. For red mullet, with the exception of the 44D codend, all other experimental codends had L_{50} values estimated below the *MCRS* of the species (13 cm TL). In whiting, except for the *40D*, all other experimental codend's L_{50} values were estimated above the *MCRS* of the species (13 cm TL).

The majority of the population entering the trawl codend consisted of individuals below the MCRS for both red mullet and whiting (Figure 3).

Compared to the conventional codend (40D), all experimental codends demonstrated a statistically significant opportunity for escape across different size groups (6.0–12.0 cm in 40S; 6.0–11.0 cm in 40T; and 6.0–14.0 cm in 44D) for red mullet (Figure 4A). In whiting, all comparisons showed significant differences in different length class, such as 9.5–16.0 cm in *40S*, 9.5–16.0 cm in 40T and 10.0–17.5 cm in *44D* (Figure 4B). In general, all experimental codends made a statistically significant contribution to the escape rates of fish below the *MCRS* length in different size classes in both species compared to the commercial codend.

In red mullet, the lowest discard ratio values were observed for the 40S and 40T codends, while the highest were observed for the *40D* and *44D* codends. The experimental codends (*40S, 40T, 44D*) demonstrated significantly lower catching efficiency for codends below the MCRS (nP^{-}), with no overlap in their confidence intervals (CIs) compared to those of the commercially used codend (40D) (Table 4). Except for *40T*, the catching efficiency of codends above the *MCRS* (nP^{+}) of the other experimental codends were lower than those of the control codend (*40D*).

For whiting, the minimum discard ratio of 59.03% was observed in *40S*, while the maximum ratio of 82.95% was found in *40D*. The experimental codends (*40S, 40T, 44D*) exhibited quite lower catching efficiency of codends below the *MCRS* (nP^{-}) values compared to the control codend (*40D*) in the whiting fishing (Table 4). The catch efficiency of codends above the *MCRS* (nP^{+}) values of experimental codends (*40S, 40T, 44D*) were lower than those of the control codend (*40D*).

Discussion

This study provides the first comprehensive assessment of codend selectivity for red mullet (*Mullus barbatus*) and whiting (*Merlangius merlangus*) in the western Black Sea, addressing a critical knowledge gap in regional fisheries management. The findings highlight the inadequacy of the currently used 40 mm diamond mesh (40D) codend for sustainable fisheries management. The retention probability of undersized individuals at the Minimum Conservation Reference Size (MCRS) was alarmingly high for both species, with 97.90% for red mullet and 82.95% for whiting. These results clearly indicate that the continued use of 40D codends would exacerbate bycatch issues, hinder sustainability, and negatively impact stock recovery efforts.

The results of this study demonstrate that alternative codend configurations, such as the 44 mm diamond mesh (44D), 40 mm square mesh (40S), and 40 mm turned mesh (40T), significantly improve size selectivity compared to the 40D codend. Among these, the 44D codend exhibited higher L_{50} values for red mullet (13.30 cm, 95% CI: 12.54–14.36) and whiting (13.65 cm, 95% CI: 12.49–14.24), confirming previous studies that increasing mesh size enhances selectivity (Sala et al., 2007; Tokaç et al., 2004). However, the 44D codend also revealed a trade-off between conservation and economic viability, particularly for red mullet, where the proportion of marketable fish retained (nP^{+}) dropped to 53.81%. This indicates that while larger mesh sizes may reduce bycatch, they also result in the escapement of legal-sized fish, which could undermine fisher compliance with regulations.

Table 2. The summary of the AIC (Akaike, 1974) values, derived from the applied selectivity models by codend for red mullet and whiting in the western Black Sea (the smallest AIC values are indicated in bold)

Codends	Species	Basic models				Additional models			
		Logistic	Probit	Gompertz	Richards	CLogit	DLogit	TLogit	Poly4
Red mullet	40D	2200.52	2200.51	2205.55	2200.37	2198.48	**2197.99**	2201.96	2203.37
	40S	**389.26**	391.14	396.86	391.22	402.41	394.96	400.03	395.85
	40T	226.28	229.91	233.23	**220.97**	223.28	225.99	231.99	226.18
	44D	7863.89	7849.91	7845.78	7847.82	7877.86	**7845.79**	7851.99	7850.73
Whiting	40D	17894.96	17879.93	17876.83	17857.83	17906.72	17803.99	**17794.63**	17853.7
	40S	8977.09	9003.78	9044.79	8976.13	9020.54	8971.72	**8955.72**	8971.42
	40T	8755.67	8765.65	8780.94	8746.20	8786.49	8721.48	**8717.72**	8748.78
	44D	18742.10	18753.73	18853.74	18739.27	18751.51	18730.47	**18727.45**	18731.45

Table 3. Selectivity parameters and fit statistics for red mullet and whiting in the experiments conducted in the western Black Sea. SR: selection range; df: degrees of freedom. The values in parentheses are the Efron's 95% CIs)

Species	Codends	L_{50} (cm)	SR (cm)	p-value	Deviance	df
Red mullet	40D	8.55 (8.02–8.93)	6.84 (2.03–12.37)	0.2730	12.18	10
	40S	12.04 (11.03–12.80)	1.66 (1.04–3.36)	0.5203	13.08	14
	40T	11.46 (10.11–11.99)	0.87 (0.53–1.82)	0.3916	10.57	10
	44D	13.23 (12.69–13.71)	2.99 (1.77–3.57)	0.0001	43.97	13
Whiting	40D	10.06 (8.59–12.58)	3.05 (2.01–3.85)	0.0001	60.47	16
	40S	15.61 (14.74–16.24)	1.54 (1.17–2.19)	0.0547	29.31	18
	40T	15.45 (14.48–15.54)	1.14 (0.45–1.14)	0.0573	27.05	17
	44D	13.56 (12.63–14.11)	4.60 (1.84–27.48)	0.0001	61.70	19

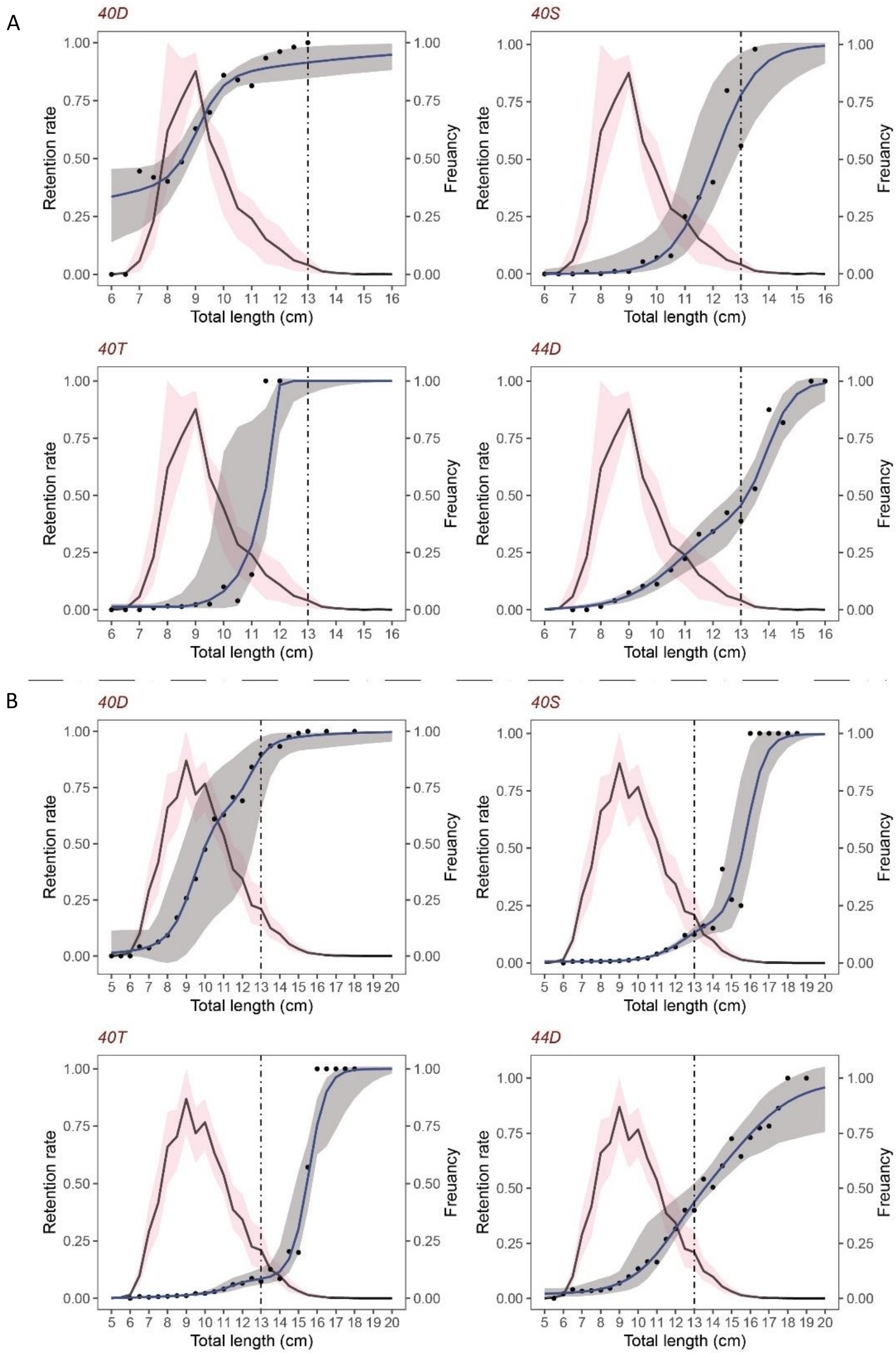

Figure 3. Selectivity curves with Efron's (1982) confidence intervals for red mullet (A) and whiting (B*)* in the western Black Sea (black lines: selection curves, vertical dashed lines: *MCRS,* light pink areas: 95% *CIs*), blue lines: size distribution of the populations of each species, and light grey areas: 95% *CIs* of the population size structure).

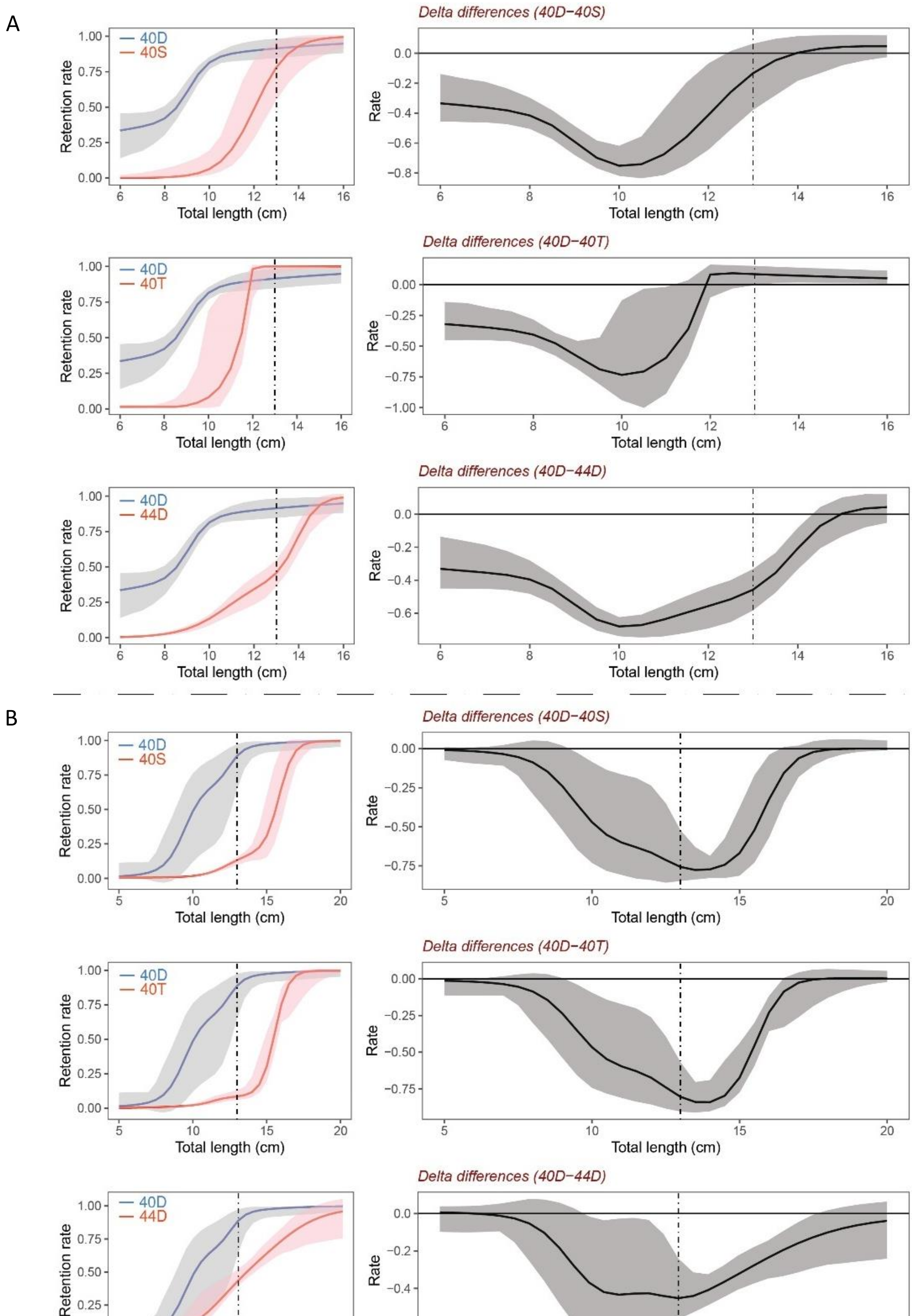

Figure 4. Delta difference curves for red mullet (A) and whiting (B) in the western Black Dea for each pairwise comparison between the commercially used codend *40D* and the experimental codends *44D*, *40S*, and *40T* (black curves indicate the fitted delta curves and dark grey areas describe the 95% *CIs*).

In contrast, the square mesh (40S) and turned mesh (40T) codends demonstrated superior performance in terms of selectivity. For red mullet, the 40S codend achieved an L_{50} value of 12.04 cm (95% CI: 11.03–12.80) with the lowest nP^- value (6.73%, 95% CI: 1.73–16.13), indicating minimal retention of undersized fish. Similarly, the 40T codend provided comparable L_{50} values (11.46 cm, 95% CI: 10.11–11.599) with the highest nP^+ value (100%). For whiting, both 40S and 40T codends achieved the highest L_{50} values (15.45 cm for 40T and 15.61 cm for 40S) and were significantly more effective than 40D (10.06 cm, 95% CI: 8.59–12.58) and 44D (13.56 cm, 95% CI: 12.63–14.11). These results indicate that square and turned mesh configurations are more effective at allowing the escape of undersized individuals while retaining marketable-sized fish.

The dramatic reduction in discard rates achieved through alternative codend configurations represents substantial progress toward sustainable fishing practices. The discard rate for red mullet decreased from 97.90% with the 40D codend to 84.57% with the 40S codend, while for whiting, the discard rate dropped from 82.95% to 59.03%. These improvements are particularly significant given the overfished status in the Black Sea (FAO, 2023). The enhanced escapement of juvenile individuals through improved codend designs directly addresses one of the primary concerns in bottom trawl fisheries: the capture and subsequent mortality of undersized specimens. By allowing improved recruitment to spawning stocks, these modifications could contribute to stock recovery and the long-term sustainability of the fishery.

However, the trade-off between conservation benefits and economic viability remains a fundamental challenge. Escaping market-sized fish, as observed with the 44D codend, reduces immediate yields and may discourage fishers from adopting more selective gears. Financial incentives, such as subsidies or compensation schemes, could play a critical role in facilitating the transition to more sustainable practices. Additionally, complementary measures, including spatial-temporal restrictions and the use of escape panels or grids, may enhance conservation outcomes while maintaining economic feasibility.

The observed differences in selectivity among codends can be attributed to several factors, including mesh geometry, material properties, twine thickness, and rigging specifications. Diamond mesh codends tend to close under tension during towing, reducing the escape area and trapping smaller fish. In contrast, square mesh codends maintain an open geometry, facilitating the escape of undersized individuals. This phenomenon has been widely documented in other studies, particularly for red mullet in the Mediterranean (Lucchetti et al., 2021; Stewart, 2002). The turned mesh configuration (T90) also showed promise, as its orientation prevents the mesh from closing under load, thereby improving selectivity for round-bodied fish like red mullet and whiting (Bayse et al., 2016). Conversely, whiting exhibited optimal selectivity performance with both 40S and 40T configurations, likely due to its elongated body morphology and enhanced swimming capacity (Steinhausen et al., 2005; Özbilgin, 2002). Our findings are consistent with previous studies in the Black Sea region (Table 5, Table 6). For example, Kaykaç et al. (2018) reported L_{50} values of 9.79 cm, 11.89 cm, and 10.29 cm for 40 mm diamond, square, and turned mesh codends, respectively, which align with our results for 40D (8.47 cm), 40S (12.30 cm), and 40T (11.45 cm). However, Ceylan and Şahin (2019) found higher L_{50} values (12.98 cm for 40D and 13.77 cm for 40S), likely due to differences in codend material (polyamide vs. polyethylene) and twine thickness. Thinner twine and more flexible materials, such as polyamide, have been shown to enhance selectivity by increasing mesh opening (Tokac et al., 2004; Sala et al., 2007). Additionally, towing duration can significantly influence selectivity, as longer tows increase catch accumulation, altering codend geometry and mesh opening (Campos et al., 2003; Suuronen et al., 1991). Our standardized 30-minute towing duration minimizes this effect, providing reliable baseline data for the region. The morphology and swimming behaviour of the target species also play a critical role in determining selectivity. For instance, the elongated body morphology and enhanced swimming capacity of whiting (Steinhausen et al., 2005; Özbilgin, 2002) likely contribute to its higher escapement rates through square and turned mesh codends. This highlights the importance of considering species-specific

Table 4. Fishing efficiency indicators for red mullet and whiting in the western Black Sea. Fishing percentage of retained specimens below (*nP^-*) and above (*nP^+*) the specific *MCRS* (13 cm) and the subsequent *nDiscardRatio* (The values in parentheses indicate the Efron's 95% CIs)

Species	Codends	Parameters		
		nP^- (%)	nP^+ (%)	nDiscardRatio (%)
Red mullet	40D	63.50 (53.54–70.57)	91.87 (84.98–98.45)	97.90 (96.38–99.52
	40S	6.73 (1.73–16.13)	82.88 (61.58–97.74)	84.57 (77.77–93.66)
	40T	10.48 (-0.33–32.53)	100.00 (95.16–100.52)	87.61 (80.72–95.94)
	44D	9.77 (5.88–13.19)	53.81 (44.77–62.12)	92.46 (87.43–97.90)
Whiting	40D	37.21(9.52–60.86)	92.96 (77.74–98.45)	82.95 (65.60–90.32
	40S	2.30 (1.67–2.94)	19.41 (14.41–25.80)	59.03 (51.50–70.53)
	40T	2.45 (1.59–3.51)	14.84 (10.70–24.66)	66.76 (56.13–77.84)
	44D	12.11 (7.29–22.99)	51.51 (46.66–59.06)	74.09 (64.70–85.10)

Table 5. Parameters obtained from demersal trawl codend selectivity studies for red mullet in the Black Sea

Material	Mesh size	Mesh type	L_{50} (cm)	*CI*	*SR*	Rigging ratio	Used model	Study area	Gear	Selectivity	Reference
PE	40	Diamond	13.22	-	3.18	-	-	-	-	-	Zengin et al. (1997)
PE	44	Diamond	13.79	-	3.23	-	-	-	-	-	Zengin et al. (1997)
PE	40	Diamond	12.01	-	3.50	0,75	Logit	Ordu-Samsun	800 mesh traditional	Covered codend	Özdemir (2006)
PE	40	Square	11.89	-	1.26	0.5	Logit	Samsun	900 mesh modified	Covered codend	Kaykac et al. (2018)
PE	40	Diamond	9.79	-	2.20	1	Logit	Samsun	900 mesh modified	Covered codend	Kaykac et al. (2018)
PE	40	T90	10.29	-	1.92	1	Logit	Samsun	900 mesh modified	Covered codend	Kaykac et al. (2018)
PA	40	Diamond	12.98	-	2.83	0.60	Logit	Sakarya	-	Covered codend	Ceylan and Şahin (2019)
PA	40	Square	13.77	-	3.02	0.60?	Logit	Sakarya	-	Covered codend	Ceylan and Şahin (2019)
PA	50	Diamond	15.24	-	2.71	0.75	Logit	Sakarya	-	Covered codend	Ceylan and Şahin (2019)
PA	40	Front Square panel	13.81	-	2.62	0.60	Logit	Sakarya	-	Covered codend	Ceylan and Şahin (2019)
PA	40	Rear Square panel	13.83	-	3.93	0.60	Logit	Sakarya	-	Covered codend	Ceylan and Şahin (2019)
PE	44	Diamond	12.88	12.54–14.36	4.89	1	Gompertz	Kocaali-Kırklareli	900 mesh modified	Covered codend	This study
PE	40	Diamond	8.47	7.92–8.81	2.94	1	Logit	Kocaali-Kırklareli	900 mesh modified	Covered codend	This study
PE	40	Square	12.30	10.52–14.52	2.16	0.5	Probit	Kocaali-Kırklareli	900 mesh modified	Covered codend	This study
PE	40	T90	11.45	10.38–16.66	0.52	0.5	Richard	Kocaali-Kırklareli	900 mesh modified	Covered codend	This study

Table 6. Parameters obtained from demersal trawl codend selectivity studies for whiting in the Black Sea

Material	Mesh size	Mesh type	L_{50} (cm)	*CI*	*SR*	Rigging ratio	Used model	Study area	Gear	Selectivity	Reference
PE	44	Diamond	15.27	-	4.13	-	Pope et al., 1975	Trabzon	-	Covered codend	Zengin and Düzgüneş (1999)
PE	44	Square	16.03	-	4.83	-	Pope et al., 1975	Trabzon	-	Covered codend	Zengin and Düzgüneş (1999)
PE	40	Diamond	13.54	-	-	-	Length distribution	Sinop	-	Codend	Genç et al. (2002)
PE	40	Square	12.57	-	-	-	Length distribution	Sinop	-	Codend	Genç et al. (2002)
PE	40	Square	15.74	-	1.81	0.5	Logit	Samsun	900 mesh modified	Covered codend	Zengin et al. (2019)
PE	40	Diamond	10.18	-	2.59	1	Logit	Samsun	900 mesh modified	Covered codend	Zengin et al. (2019)
PE	40	Diamond	10.25	8.49–12.29	2.80	1	Logit	Kocaali-Kırklareli	900 mesh modified	Covered codend	This study
PE	40	Square	16.23	15.70–17.01	3.53	0.5	Probit	Kocaali-Kırklareli	900 mesh modified	Covered codend	This study
PE	40	T90	16.27	16.01–16.88	2.23	0.5	Richard	Kocaali-Kırklareli	900 mesh modified	Covered codend	This study
PE	44	Diamond	13.65	12.49–14.24	4.43	1	Gompertz	Kocaali-Kırklareli	900 mesh modified	Covered codend	This study

characteristics when designing and implementing selective fishing gears.

While this study provides valuable insights into codend selectivity, several limitations should be acknowledged. The seasonal timing of data collection (July) may not fully capture year-round variations in fish behaviour and morphometric characteristics. Additionally, the relatively short towing durations (30 minutes) employed in this study, while standardized for experimental consistency, may not fully replicate commercial fishing conditions, where longer tows and higher catch volumes are common. Longer tows can alter codend geometry and mesh opening, potentially affecting selectivity (Campos et al., 2003; Suuronen et al., 1991). Future research should address these limitations by conducting: (i) Seasonal selectivity assessments to capture temporal variations, (ii) Evaluations of selectivity under varying catch volumes and tow durations, (iii) Assessments of alternative selective devices, such as escape panels and grids (iv) Economic impact analyses to support industry transition, and (v) Long-term monitoring of stock responses to improved selectivity measures.

The successful implementation of improved selectivity measures will require careful consideration of industry acceptance, economic impacts, enforcement mechanisms, and monitoring protocols. Transition strategies that gradually introduce more selective gears while providing financial and technical support for fishers are essential. Pilot implementation of 40S or 40T codends in selected areas could provide valuable insights into their practical performance under commercial conditions. Furthermore, stakeholder engagement and education will be critical to ensuring compliance and fostering a shared commitment to sustainable fisheries management.

Conclusion

This study demonstrates that the currently used 40D codend is inadequate for sustainable fisheries management in the western Black Sea. Substantial improvements in selectivity for red mullet and whiting can be achieved through relatively simple modifications to existing gear configurations, adopting 40S, 40T or 44D codends. These configurations offer a practical approach to reducing juvenile mortality while maintaining economic viability.

However, successful adoption will require a comprehensive management strategy that includes financial incentives, stakeholder engagement, and robust monitoring programs. We recommend: (i) pilot implementation of 40S codends in selected areas to evaluate practical performance, (ii) development of economic support mechanisms to facilitate industry transition, (iii) establishment of monitoring programs to assess conservation outcomes, and (iv) continued research to optimize selective technologies for regional conditions. These measures, implemented as part of a comprehensive management strategy, could contribute significantly to the sustainable exploitation of Black Sea demersal resources.

The primary outcome of the study is that it offers a scientific basis for the legal requirement to adopt 44D bags in place of 40D bags, a regulation scheduled for implementation in 2028. The study also found that the average L50 values of 44D bags in both red mullet and whiting fishing are above the Minimum Conservation Reference Size (MCRS).

Ethical Statement

Since no experimental animal was used in the submitted study, approval of the ethics committee is not required.

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Author Contribution

Hamdi Moussa: Project administration, Funding acquisition, Investigation. Mehmet Cilbiz: Formal analysis, Software, Visualization. Uğur Uzer: Writing–review & editing, Validation. Celalettin Aydin: Data curation, Methodology, Validation. Taner Yildiz: Writing–original draft. İbrahim Tamer Emecan: Writing–review & editing, Investigation. F. Saadet Karakulak: Supervision, Project administration, Funding acquisition.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

References

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, 19(6), 716-723.

Alverson, D.L. (1997). Global assessment of fisheries bycatch and discards: a summary overview, Global Trends. *Fisheries Management American Fisheries Society Symposium,* 20, 115-125.

Alverson, D.L. & Hughes, S.E. (1996). By-catch: from emotion to effective natural resource management. *Review in Fish Biology and Fisheries,* 6, 443-442.

Anonymous. (2024). 6/1 Notification of commercial fish catching regulation in seas and inland waters (Notification number 2024/20). Republic of Türkiye, Minister of Agriculture and Forestry, General Directorate of Fisheries and Aquaculture, Ankara

Asciutto, R., Liguori, T., Mariani, A., & Rossi, G. (2024). Habitat preferences and biomass patterns of whiting (*Merlangius merlangus*) in the northern Adriatic Sea. PLOS ONE, 19(3), e0289999.

Aydın, İ., Eroğlu, O., & Küçük, E. (2008). Karadeniz'in demersal balıkları. SUMAE Yunus Araştırma Bülteni, 8(2), 7-13.

Bayse, S. M., Herrmann, B., Lenoir, H., Depestele, J., Polet, H., Vanderperren, E., & Verschueren, B. (2016). Could a T90 mesh codend improve selectivity in the Belgian beam trawl fishery? *Fisheries Research*, 174, 201-209.

Bilgin, S., Bal, H., & Taşçı, B. (2012). Length Based Growth Estimates and Reproduction Biology of Whiting (*Merlangius merlangus euxinus*) in the Southeast Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 12(4), 871–881.

Brčić, J., Herrmann, B. & Sala, A. (2018). Predictive models for codend size selectivity for four commercially important species in the Mediterranean bottom trawl fishery in spring and summer: Effects of codend type and catch size. *PLOS ONE*, *13*(10), e0206044.

Broadhurst, M. K. (2000). Modifications to reduce bycatch in prawn trawls: a review and framework for development. *Reviews in Fish Biology and Fisheries*, *10*, 27-60.

Campos, A., Fonseca, P. & Erzini, K. (2003). Size selectivity of diamond and square mesh cod ends for four by-catch species in the crustacean fishery off the Portuguese south coast. *Fisheries Research* 60, 79–97. https://doi.org/10.1016/S0165-7836(02)00061-9

Catchpole, T. L. & Gray, T. S. (2010). Reducing discards of fish at sea: a review of European pilot projects. *Journal of Environmental Management,* 91(3), 717-723. https://doi.org/10.1016/j.jenvman.2009.09.035

Cerbule, K., Herrmann, B., Brčić, J., Grimaldo, E., & Bak-Jensen, Z. (2024). Selectivity in snow crab (*Chionoecetes opilio*) pot fishery: Effect of escape gap shape and size for conservation of fishery resources. Journal for Nature Conservation, 79, 126616. https://doi.org/https://doi.org/10.1016/j.jnc.2024.126616

Ceylan, Y., & Sahin, C. (2019). Selectivity of Different Alternative Cod Ends and Radial Square Mesh Escape Panels (RSEP). *Turkish Journal of Fisheries and Aquatic Sciences*, 19 (6), 451-461.

Cheng, Z., Einarsson, H.A., Bayse, S., Herrmann, B. & Winger, P. (2019). Comparing size selectivity of traditional and knotless diamond-mesh codends in the Iceland redfish (*Sebastes spp*.) fishery. *Fisheries Research*, 216, 138-144.

Crowder, L.B. & Murawski, S.A. (1998). Fisheries bycatch: Implications for management. *Fisheries*, 23, 8-17.

E.C. (2006). Council Regulation (EC 1967/2006) concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, amending Regulation (EEC) No 2847/93 and repealing Regulation (EC) No 1626/94. Off. J.E.U. 409, 75 p.

Efron, B. (1982). The Jackknife, the Bootstrap and Other Resampling Plans. CBMS-NSF Regional Conference Series in Applied Mathematics, Monograph 38, SIAM, Philadelphia.

Einarsson, H. A., Cheng, Z., Bayse, S. M., Herrmann, B., & Winger, P. D. (2021). Comparing the size selectivity of a novel T90 mesh codend to two conventional codends in the northern shrimp (*Pandalus borealis*) trawl fishery. Aquaculture and Fisheries, 6(4), 382-392. https://doi.org/https://doi.org/10.1016/j.aaf.2020.09.005

FAO. 2023. The State of Mediterranean and Black Sea Fisheries 2023 – Special edition. General Fisheries Commission for the Mediterranean. Rome. https://doi.org/10.4060/cc8888en

Fonteyne, R., Buglioni, G., Leonori, I. & O'Neill, F.G. (2007). Review of mesh measurement methodologies. *Fisheries Research*, 85 (3), 279–284

Frandsen, R.P., Herrmann, B. & Madsen, N. (2010). A simulation-based attempt to quantify the morphological component of size selection of *Nephrops norvegicus* in trawl codends. Fish. Res. 101, 156–167.

Genç, Y. (2000). Population parameters and bio-ecological features of the red mullet (mullus barbatus ponticus, Ess. 1927) stocks from the Eastern Black sea coast of Turkey. PhD Thesis. Karadeniz Teknik Üniversitesi, Trabzon, Türkiye.

Genç, Y., Mutlu, C. Zengin, M., Aydın, İ., Zengin, B. & Tabak, İ. (2002). Determining of Fishing power effect on demersal fish stock in eastern Black Sea TAGEM/IY/97 /17/03/006 (Unpublished project final report) [in Turkish], Central fisheries research Institute Trabzon, Türkiye 122 pp.

Herrmann, B., Krag, L.A. & Krafft, B. A. (2018). Size selection of Antarctic krill (*Euphausia superba*) in a commercial codend and trawl body. *Fisheries Research*, *207*, 49-54.

Herrmann, B., Sistiaga, M.B., Nielsen, K.N. & Larsen, R.B. (2012). Understanding the size selectivity of redfish (*Sebastes spp*.) in North Atlantic trawl codends. *Journal of Northwest Atlantic Fishery Science*, 44 (1), 13.

Kalogirou, S., Pihl, L., Maravelias, C. D., Herrmann, B., Smith, C. J., Papadopoulou, N., ... & Sala, A. (2019). Shrimp trap selectivity in a Mediterranean small-scale-fishery. *Fisheries Research*, 211, 131-140.

Kasapoğlu, N. (2018). Age, growth, and mortality of exploited stocks: Anchovy, sprat, Mediterranean horse mackerel, whiting, and red mullet in the southeastern Black Sea. Aquatic Sciences and Engineering, 33(2), 39–49.

Kaykac, M.H., Zengin, M. & Tosunoglu, Z. (2018) Can Shifting Codend Mesh Shape and Mesh Size Increase the Size Selectivity of Red mullet (*Mullus barbatus*) in the Black Sea?, *Turkish Journal of Fisheries and Aquatic Sciences,* 18 (7), 859–870.

Kazemi Kelleher, S.H., Paighambari, S.Y. & Abaspour Naderi, R. (2014). By-catch and Discard composition of dhow Penaeid Trawl Fisheries in Hormuzgan Province, the Northern Persian Gulf. *J. Persian Gulf (Marine Science*), 5, 49-56

Krag, L.A., Herrmann, B., Karlsen, J.D. & Mieske, B. (2015). Species selectivity in different sized topless trawl designs: does size matter? Fish. Res. 172, 243–249. https://doi. org/10.1016/j.fishres.2015.07.010.

Krag, L. A., Melli, V., O'Neill, F. G., Hansen, K., & Karlsen, J. D. (2025). DragLess - a holistic approach to gear development: reducing roundfish bycatch and drag in the trawl fishery of Norway lobster (*Nephrops norvegicus*) off Denmark. Ocean and Coastal Management, 267, Article 107722. https://doi.org/10.1016/j.ocecoaman.2025.107722

Lipovetsky, S. (2010). Double logistic curve in regression modeling. Journal of Applied Statistics. 37, 1785–1793. https://doi.org/10.1080/02664760903093633.

Lucchetti, A., Virgili, M., Vasapollo, C., Petetta, A., Bargione, G., Li Veli, D., Brĉic, J. & Sala, A. (2021). An overview of bottom trawl selectivity in the Mediterranean Sea. *Mediterranean Marine Science*, 22(3), 566-585. https://doi.org/10.12681/mms.26969

Machias, A., Tsimenides, N., & Kallianiotis, A. (1998). Bathymetric distribution and movements of red mullet *Mullus surmuletus*. Marine Ecology Progress Series, 166, 247–257.

Melli, V., Herrmann, B., Karlsen, J.D., Feekings, J.P. & Krag, L.A. (2020). Predicting optimal combinations of by-catch reduction devices in trawl gears: A meta-analytical approach. *Fish and Fisheries*, 21(2), 252-268.

Mikeladze, R., Makharadze, G., Joglidze, T., Vadachkoria, P., Salukvadze, L., Leonchyk, Y., & Snigirov, S. (2023). Red Mullet (*Mullus barbatus ponticus* Essipov, 1927) Stock Exploitation in Georgian Coastal Waters (2019-2021). Turkish Journal of Fisheries and Aquatic Sciences, 23(SI).

Millar, R.B. (1993). Incorporation of between-haul variation using bootstrapping and. *Fishery Bulletin*, 91, 564-572.

Millar, R.B. & Fryer, R.J. (1999). Estimating the Size Selection Curves of Towed Gears, Traps, Nets, and Hooks. *Review in Fish Biology and Fishery*, 9, 89-116. https://doi.org/10.1023/A:1008838220001

Mytilineou, C., Herrmann, B., Kavadas, S., Smith, C. J.& Megalofonou, P. (2020). Combining selection models and population structures to inform fisheries management: a case study on hake in the Mediterranean bottom trawl fishery. *Mediterranean Marine Science*, 21(2), 360-371. https://doi.org/10.12681/mms.22191

Özbilgin, H. (2002). Effect of temperature change on maximum swimming speed of whiting Merlangius merlangus (Linnaeus, 1758). *Turkish Journal of Zoology*, 26, 255–262.

Özdemir, S. (2006). The effect of position and mesh size of square mesh panel applied in bottom trawl on catchability of different species. PhD thesis, Samsun: Ondokuz Mayıs University, Science Institute, Türkiye. [In Turkish.]

Posit team. (2025). RStudio: Integrated Development Environment for R.Posit Software, PBC, Boston, MA. URL http://www.posit.co/.

Sala, A., Herrmann, B., De Carlo, F., Lucchetti & A., Brčić, J. (2016). Effect of Codend Circumference on the Size Selection of Square-Mesh Codends in Trawl Fisheries. *PLOS ONE*, *11*(7), e0160354.

Sala, A., Lucchetti, A. & Buglioni, G. (2007). The influence of twine thickness on the size selectivity of polyamide codends in a Mediterranean bottom trawl. *Fisheries Research*. 83 (2007) 192–203

Santos, J., Herrmann, B., Mieske, B., Stepputtis, D., Krumme, U., & Nilsson, H. (2016). Reducing flatfish bycatch in roundfish fisheries. *Fisheries Research*, 184, 64-73. https://doi.org/10.1016/j.fishres.2015.08.025

Santucci, R. G., Tosunoğlu, Z., Cilbiz, M., Charles, S. K., Gireesh, S., Kadengal, S. T., Adam, A. M. S., Tıraşın, E. M., Ünal, V., & Dimech, M. (2024). Assessing Codend Mesh Selectivity: Comparing Diamond and Square Mesh Codend in the Red Sea Shrimp Trawl Fishery of Saudi Arabia. Journal of Marine Science and Engineering, 12(10), 1848. https://doi.org/10.3390/jmse12101848

Sistiaga, M., Herrmann, B., Grimaldo, E., & Larsen, R. B. (2010). Assessment of dual selection in grid based selectivity systems. Fisheries Research, 105(3), 187–199. https://doi.org/10.1016/j.fishres.2010.05.006

Steinhausen, M.F., Steffensen, J.F. & Andersen, N.G. (2005). Tail beat frequency as a predictor of swimming speed and oxygen consumption of saithe (*Pollachius virens*) and whiting (*Merlangius merlangus*) during forced swimming. *Marine Biology*, 148, 197–204.

Stewart, P.A.M. (2002). A review of studies of fishing gear selectivity in the Mediterranean. FAO COPEMED, 57 pp.

Suuronen, P., Millar, R.B. & Jarvik, A. (1991). Selectivity of diamond and hexagonal mesh codends in pelagic herring trawls: evidence of a catch size effect. *Finnish Fisheries Research,* 12, 143–156

Tokaç, A., Özbilgin, H. & Tosunoğlu , Z. (2004). Effect of PA and PE material on codend selectivity in Turkish bottom trawl. *Fisheries Research,* 67, 317–327.

Turkstat. (2025). Fisheries production statistics for 2024. Ankara, Turkey. Available at https://biruni.tuik.gov.tr/meda/?kn=97&locale=tr (accessed 05 June 2025).

UN (2023). GFCM Draft Contribution to UN-RES 74/18. Available at. https://www.un.org/Depts/los/bfw-/GFCM%20Bottom%20Fishing%20Contribution.pdf (accessed 05 May 2023).

Whitehead, P.J.P., Bauchot, M.-L., Hureau, J.-C., Nielson, J. & Tortonese, E. (1986). *Fishes of the North-eastern Atlantic and the Mediterranean. Vol. I, II & III.* Paris: United Nations Educational, Scientific and Cultural Organisation (UNESCO).

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

Wienbeck, H., Herrmann, B., Moderhak, W., & Stepputtis, D. (2011). Effect of netting direction and number of meshes around on size selection in the codend for Baltic cod (*Gadus morhua*). *Fisheries Research*, 109(1), 8088. https://doi.org/10.1016/j.fishres.2011.01.019

Wileman, D.A., Ferro, R.S T., Fonteyne, R. & Millar, R.B., (Editors)., 1996. Manual of Methods of Measuring the Selectivity of Towed Fishing Gears. *ICES Cooperatıve Research Report No.* 215, 126p.

Yildiz T. (2016). The effect of trawl fishery on commercial demersal fish stocks in the western Black Sea. PhD Thesis. Istanbul University, pp 225. [in Turkish]

Yildiz, T. & Karakulak, F.S. (2016). An investigation of age, growth and mortality of the red mullet (*Mullus barbatus* Linnaeus, 1758) in the western Black Sea. *Cahiers De Biologie Marine*, 57, 415-425.

Yildiz, T. & Karakulak, F.S. (2019). Age, Growth and Mortality of Whiting (*Merlangius merlangus* Linnaeus, 1758) from the Western Black Sea, Turkey. *Turkish Journal of Fisheries and Aquatic Sciences,* 19 (9), 793-804

Yildiz, T., Uzer, U., Yemişken, E., Karakulak, F. S., Kahraman, A. E., & Çanak, Ö. (2021). Conserve immatures and rebound the potential: stock status and reproduction of whiting (*Merlangius merlangus* [Linnaeus, 1758]) in the Western Black Sea. Marine Biology Research,17 (9-10),815-827.

Zengin, M., Akpınar, İ.Ö., Kaykaç, M.H. & Tosunoğlu, Z. (2019). Comparison of selectivity of the trawl codends for whiting (*Merlangius merlangus euxinus*) in the Black Sea. *Ege Journal of Fisheries and Aquatic Sciences*, 36 (3), 301-311.

Zengin, M. & Düzgüneş E., (1999). Determination of the bottom trawl selectivity used in the catching of the whiting (*Merlangius merlangus* euxinus Nord 1840) in the Black Sea. *İstanbul University of Fisheries Faculty*, Special Issue, 535-547.

Zengin, M., Genç, Y. & Tabak, İ., (1997). Determination of the selectivity of bottom trawl. Republic of Turkey, Minister of Agriculture and Rural Affairs TAGEM/IY/96/12/1/004 (Unpublished project final report) [in Turkish], Central fisheries research Institute Trabzon, Türkiye 51 pp.