Effect of mesh size in monofilament and multifilament gillnets on catch efficiency in the Black Sea whiting (*Merlangius merlangus*) fishery

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Abstract

Gillnets are widely used fishing gear for targeting various fish species. Gillnet fisheries use different gear configurations such as different mesh sizes and number of netting twines (mono- or multifilament) depending on the species targeted. Gillnet fishery targeting whiting (*Merlangius merlangus*) is one of the economically important year-round fisheries in the Black Sea. However, large bycatch of whiting below minimum landing size (MLS) has led to a stock decrease, questioning sustainability of this fishery. This study evaluated how netting twine construction and mesh size can affect the capture probability of whiting. The results showed that changes in gillnet mesh size significantly affect the capture probability with increased mesh size reducing the average capture probability of undersized whiting from around 60% to 5%. The results showed no significant differences in the average catch efficiency between monofilament and multifilament gillnets of the same mesh sizes; however, monofilament gillnets showed an increased catch efficiency for some length classes of whiting >MLS. Based on these results, use of 32 or 34 mm mesh size monofilament gillnets is advisable for sustainable whiting fisheries management in the Black Sea.

Keywords: Gillnets; mesh size; monofilament; multifilament; *Merlangius merlangus;* Black Sea.

1. Introduction

Gillnets are widely used fishing gear around the world for targeting various fish species (He, 2006; He et al., 2021). Generally, gillnets are considered as a low cost, easy operation fishing gear (Suuronen et al., 2012). Therefore, gillnet fisheries support a significant proportion of small-scale fishing communities worldwide (Northridge et al., 2017). Different gear configurations such as number of twines in the gillnet netting (i.e., mono- or multifilament nets), mesh sizes and hanging ratios are used depending on the species targeted. Each such gillnet modification is affecting catchability of the gear for fishes of different sizes, morphologies, and swimming abilities (He, 2006; He et al., 2021).

Whiting (*Merlangius merlangus*) belonging to the family Gadidae is a widely distributed species, ranging from the southeastern Barents Sea and Iceland to Portugal

(Cohen et al., 1990). It is also a common species in the Black Sea, Aegean Sea, Adriatic Sea, and the adjacent areas (Froese and Pauly, 2023), inhabiting areas of muddy and gravel seafloor, while also being observed on sandy and rocky seabed in depths ranging from 30 to 100 m (Cohen et al., 1990). In the Black Sea fishery of Türkiye targeting whiting, bottom-set gillnets are one of the main small-scale fishing gears used, providing high-quality catches. Since a large part of the Turkish fishing fleet consists of a small-scale fishery, this fishing method has a high importance for the region. Furthermore, the whiting fishery is conducted all year round making it one of the main sources of livelihood for the small-scale gillnet fishery in the region.

In this fishery, the Turkish Ministry of Agriculture and Forestry has implemented a minimum landing size (MLS) of 13 cm total length for whiting. However, catches of undersized whiting constituting up to 5% of the total catch weight can be sold (TFR, 2020). The fishery uses monofilament and multifilament gillnets for targeting whiting. Use of monofilament gillnets has been banned in this fishery since 2012 with an aim of reducing undersized whiting catches. However, no scientific studies have been conducted regarding the length-dependent capture in monofilament gillnets, and the ban of using monofilament netting was removed in 2022. The fishers in this area prefer using monofilament gillnets due to claimed higher catches and easier handling when using this gillnet configuration compared to the multifilament netting. Furthermore, monofilament gillnets are less expensive and easier to repair compared to multifilament nets (Colins, 1979). Consequently, there is an interest in converting from multifilament to monofilament gillnets, including in standardized gillnet surveys (Eighani et al., 2020; Smith et al., 2022).

The current regulations require using 34 mm as the minimum mesh size (MMS) for monofilament gillnets for targeting whiting (TFR, 2020). However, there is no MMS regulation established for multifilament gillnets in this fishery to supplement the MLS and bycatch ratio regulations. The mesh size is one of the main parameters affecting the sizes of fish that can be captured in gillnets (Holst et al., 1998; Fonseca et al., 2005; Hubert et al., 2012; Shoup and Ryswyk, 2016). Therefore, alternating the gillnet mesh size could be a method for reducing catches of undersized fish and thus improving fisheries sustainability.

According to the data of the Turkish Statistical Institute, the catch amount of whiting in the last two decades has decreased from 18000 tons/year to 7287 tons/year (TURKSTAT, 2023). This is an indication that the whiting stock is being overexploited in the Black Sea. Following this stock decrease, the fishery in Black Sea Coast of Türkiye is using increasingly smaller mesh sizes in multifilament gillnets which can further negatively affect stock sizes (Kalaycı and Yeşilçiçek, 2014a). For example, while previously in the region gillnets with mesh sizes ranging from 36 and 44 mm were commonly used, currently the commercial fishery uses multifilament gillnets of 28 mm mesh size. Since the optimal MMS corresponding to the current management regulations (i.e., the MLS and bycatch ratio regulations) has not yet been scientifically established for either mono- or multifilament nets, this study aims at determining the optimal gillnet mesh size that can be used for sustainable whiting gillnet fishery.

Earlier studies have shown that in this whiting gillnet fishery the mesh size in multifilament gillnets used ranges from 28 – 44 mm while the preferred mesh size is 32 mm (Aydın, 1997; Genç et al., 2002; Kalaycı and Yeşilçiçek, 2014a). Therefore, in this study, we chose to test this mesh size and compare it with two smaller mesh sizes (28 mm and 30 mm) and two larger mesh sizes (34 mm and 36 mm). We applied similar approach to the monofilament gillnets. Therefore, our study was designed to answer the following questions:

- Are there any differences in the length-dependent capture probability of whiting between monofilament gillnets of different mesh sizes?
- Are there any differences in the length-dependent capture probability of whiting between multifilament gillnets of different mesh sizes?
- Does the length-dependent capture probability of whiting differ between monofilament and multifilament gillnets of same mesh size?
- What is the optimal gillnet construction (monofilament or multifilament netting) and mesh size for the whiting gillnet fishery corresponding to the established management regulations?

2. Materials and methods

2.1 Sea trials

Sea trials were conducted during a one-year period between 28th December 2016 and 14th December 2017 in the coastal waters of the Black Sea, Türkiye (39°33′21″ - 39°35′54″ N; 41°01′21″ - 41°03′19″ E) (Fig. 1; Supplementary material 1). The study area is a traditional commercial fishing ground for targeting whiting. The substrate type is a mixture of mud, sand, and rock, and the water depth ranges from 40 to 78 m. A commercial fishing boat "Bilo 61D1788-TUR001154676" (LOA 6.6 m, width 2.45 m, height 0.7 m, weight 1.64 GT, power 78.36 kW) was used during the sea trials.

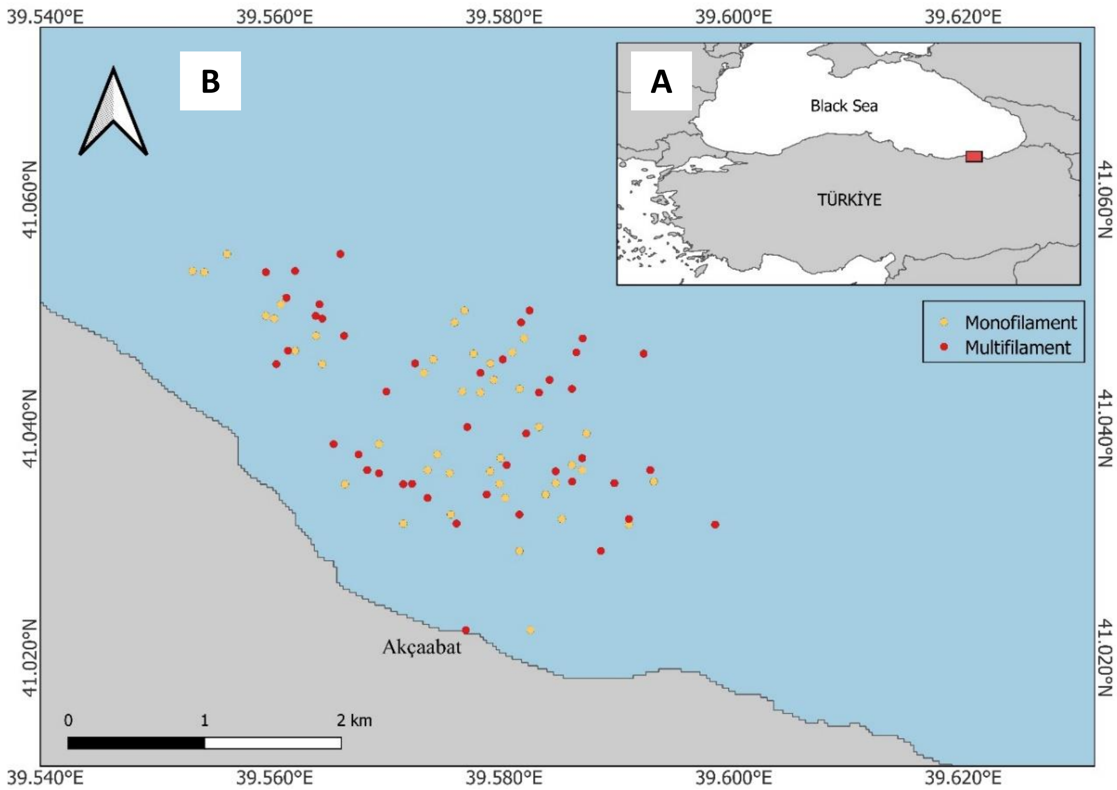

Figure 1. Area where the sea trials were conducted. (A) Map of study area off the Turkish Coast of the Black Sea where the gillnets were deployed (marked with a red square). (B) Deployment of the gillnets during the sea trials with yellow and red dots representing the deployments with monofilament and multifilament gillnets, respectively.

Gillnets with both monofilament and multifilament netting with 28, 30, 32, 34, and 36 mm nominal mesh sizes were used in these trials (herein M28, M30, M32, M34, and M36, respectively, for monofilament gillnets and ML28, ML30, ML32, ML34, and ML36, respectively, for multifilament gillnets). All monofilament gillnets were made of white nylon (polyamide; PA) monofilament with a twine thickness ranging from 0.14 to 0.15 mm while all multifilament gillnets were made of nylon multifilament with a twine thickness of 80d/2 no (Supplementary material 2). In total for both monofilament and multifilament gillnets, ten gillnet sheets were used in this study. We had one fleet for monofilament and one fleet for multifilament. Each fleet contained one sheet for each of the five different mesh sizes. The dimensions of each gillnet sheet were 125 m in length (deployment length/rope length) and 1.7 m in height with a hanging ratio (E) of 0.625 (Fig. 2; Supplementary material 2). Therefore, each fleet of monofilament and multifilament gillnets had a total length of 625 m and consisted of five gillnet sheets arranged in the following order: M28, M30, M32, M34, and M36 and ML28, ML30, ML32, ML34, and ML36, respectively (Fig. 2). The specifications of tested gillnets were identical to those used in the commercial fishery, including material, twine thickness, and gillnet sheet dimensions (Supplementary material 2). The floats were composed of plastic polyethylene (PE) and the sinkers were made of lead blocks, each weighting 30 g. Two buoys and anchors were connected to each end of the fleet.

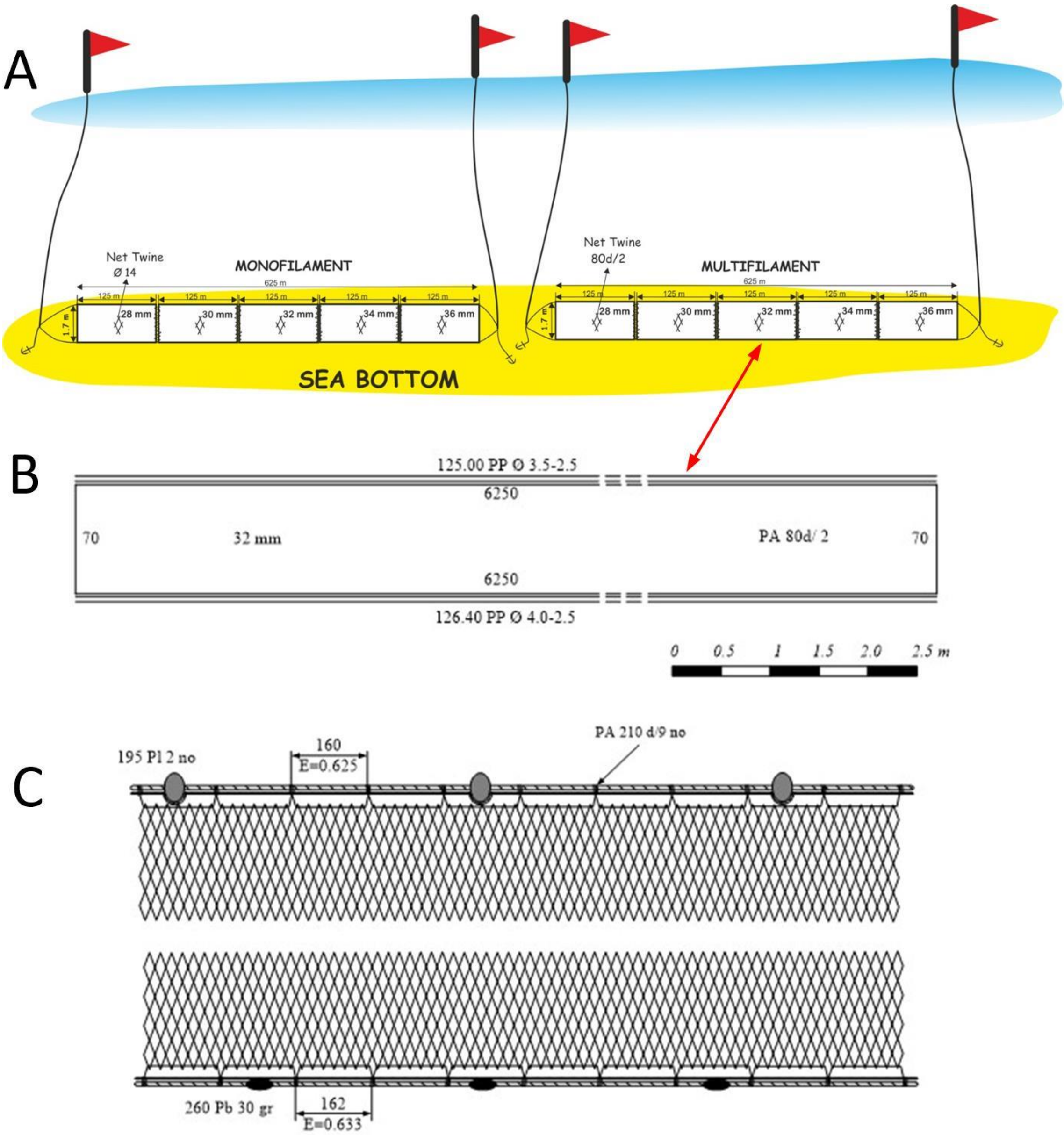

Figure 2. A schematic representation of the tested gillnets. (A) The experimental setup of gillnets with different mesh sizes (28, 30, 32, 34 and 36 mm) deployed as a fleet during the fishing trials. Monofilament and multifilament gillnets were deployed simultaneously and in the same fishing area. (B) The technical drawing showing a 32 mm multifilament gillnet which is widely used in the commercial fishery in the region. (C) Hanging ratio (E) and technical parameters of the headline and sink line.

During the trials, all gillnets were usually deployed twice a month (Supplementary material 1). However, gillnets were set once a month in May, October and November due to the sea conditions, and three times in June due to the low fish catches caused by seasonality. In each of the deployments, two gillnet fleets consisting of one monofilament and one multifilament gillnet fleet were deployed. Therefore, during 22 deployments, gillnets were set in total 44 times (Supplementary material 1). Experimental monofilament and multifilament gillnet fleets were deployed into the same fishing grounds simultaneously in succession or side by side (Fig. 2). Gillnets were set at twilight and retrieved in the morning of the following day. The soak time was adjusted according to the commercial fishing practice and ranged between 2 to 18.5 hours. The soaking time was kept similar for all gillnets in multifilament and monofilament fleets in each deployment (Supplementary material 1). After each trial, each gillnet sheet was inspected, and damaged gillnet sheets replaced. However, this did not happen frequently. The gillnets used in the experiments were replaced three times during this study due to aging, tearing, and, especially with the monofilament nets, loss of elasticity after some deployments.

After each deployment, the catches were sorted by the type of gillnet, and the total length of all whiting was measured in centimeters.

2.2 Modelling the effect of gillnet mesh size on the length-dependent capture probability

Conditioned capture, the length-dependent capture probability $CPm(l)$ by a specific mesh size m was estimated following the method in Savina et al. (2022) and Yu et al.

(2023). Specifically, the catch numbers of whiting by each of the mesh sizes and the corresponding total length were used. This analysis was conducted independent for each mesh size and separately for the monofilament and multifilament gillnets. Each deployment of all gillnet fleets in each fishing day were considered as the base unit for the analysis. Further, the pairwise differences (delta) in length-dependent capture probability between gillnets with different mesh sizes $\Delta CP(l)$ were estimated. Finally, length-integrated average values for the capture probability ($CP_{average}$) were estimated directly from the experimental catch data. Uncertainties in terms of Efron 95% confidence intervals (CIs) (Efron, 1982) were estimated by bootstrapping (Savina et al., 2022; Yu et al., 2023). Details about the estimation of $CPm(l)$, $\Delta CP(l)$ and $CP_{average}$ can be found in Supplementary material 3.

2.3 Modelling catch efficiency between monofilament and multifilament gillnets

To quantify the effect of changing from multi- to monofilament gillnets, the catch data was analysed for each mesh size separately by modelling the length-dependent catch efficiency for whiting between monofilament and multifilament gillnets of the same mesh size using the method outlined in Herrmann et al. (2017). This method models the length-dependent catch comparison rate ($CC(l)$) and catch ratio ($CR(l)$) summed over gillnet deployments during the entire experimental period. Further, we assessed whether any potential differences between multifilament and monofilament gillnets could be related to the total length of whiting. Finally, the length-integrated average values for the catch ratio ($CR_{average}$) were estimated directly from the experimental catch data. Likewise for capture probability $CPm(l)$, uncertainties were estimated by bootstrapping (Herrmann et al., 2017). Details about the estimation of $CC(l)$, $CR(l)$, and $CR_{average}$ can be found in Supplementary material 4.

2.4 Software

All the data analysis procedures described in Sections 2.2 – 2.3 were conducted using the statistical software SELNET (Herrmann et al., 2012).

3. Results

3.1 Description of experiments and catches

During a total of 22 fishing days, 44 valid gillnet fleet deployments were conducted. A total of 8513 whiting were caught, and their total lengths measured in all gillnets during the trials (Table 1).

Table 1. Summary details of the catch data of whiting (*Merlangius merlangus*) in the sea trials. *n* denotes number of whiting caught by specific gillnet sheet (M – monofilament netting; ML – multifilament netting).

Gillnet	*n*	Length (cm)	
		Minimum	Maximum
M28	1650	8.5	21.8
M30	1069	8.0	23.5
M32	582	7.4	22.9
M34	491	7.2	22.3
M36	364	5.5	24.7
ML28	1749	8.3	19.7
ML30	1000	7.0	20.6
ML32	744	6.8	20.6
ML34	412	7.0	23.8
ML36	452	8.0	25.5

3.2 Effect of gillnet mesh size on length-dependent capture probability

For all mesh sizes of monofilament gillnets, the estimated *p*-value was below 0.05 (Table 2). However, the capture probability curve represented the trends in experimental data well (Fig. 3); therefore, the low *p*-value was assumed to be due to overdispersion in the data (Wileman et al., 1996). This was also the case for multifilament gillnets where the *p*-value was below 0.05 (Table 3).

The results showed that in monofilament gillnets, M28 had a significantly higher capture probability for undersized whiting and lower capture probability of whiting above the MLS of largest length classes compared to gillnets with larger mesh sizes (Fig. 3). In contrast, for larger mesh size gillnets (i.e., M36), the capture probability of whiting below the MLS was significantly lower while the capture probability increased for the larger sized individuals above the MLS (Fig. 3). Similarly, M34 and M32 had a significantly lower probability of capturing undersized whiting. Specifically, the 95% CIs for M34 and M32 gillnets for undersized whiting was below the baseline for equal capture probability (0.2 or 20.00%) (Fig. 3). Furthermore, in M32 gillnets, no significant difference in capture probability of whiting over the MLS was shown.

Similar results were observed for multifilament gillnets where the capture probability of whiting below the MLS decreased with increasing mesh size of multifilament gillnets. Specifically, the capture probability for undersized whiting in multifilament gillnets was significantly lower in 32 mm mesh size gillnets ($CP_{average-}$= 08.21 (CI: 5.77-10.99)) compared to smaller mesh size gillnets. The capture probability for target sized individuals was not significantly different compared to 28 and 30 mm mesh size gillnets ($CP_{average+}$= 21.12 (CI: 17.07-25.32)) (Table 3). ML34 and ML36 showed decreased capture probability of undersized whiting; however, ML34 and ML36 also captured less whiting above the MLS (Table 3).

Table 2. Fit statistics of the length-dependent capture probability analysis and estimated exploitation pattern indicators (in %) for the five mesh sizes of monofilament gillnets (M28-M36). DOF denotes degrees of freedom. Values in parentheses are 95% confidence intervals.

	M28	**M30**	**M32**	**M34**	**M36**
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Deviance	163.09	115.11	12.40	74.60	96.55
DOF	31	31	31	31	31
$CP_{average-}$	60.04 (52.02-66.39)	18.69 (15.07-22.59)	9.88 (6.59-14.94)	6.44 (4.15-9.04)	4.94 (3.24-7.28)
$CP_{average+}$	33.86 (26.63-41.58)	27.73 (23.76-31.50)	15.18 (11.18-19.33)	13.35 (10.51-16.17)	9.88 (6.26-14.09)

Table 3. Fit statistics of the length-dependent capture probability analysis and estimated exploitation pattern indicators (in %) for the five mesh sizes of multifilament gillnets (ML28-ML36). DOF denotes degrees of freedom. Values in parentheses are 95% confidence intervals.

	ML28	**ML30**	**ML32**	**ML34**	**ML36**
p-value	< 0.001	0.3412	0.0228	< 0.001	< 0.001
Deviance	103.99	29.41	43.58	73.25	59.89
DOF	27	27	27	27	27
$CP_{average-}$	64.74 (57.54-70.75)	15.40 (10.71-19.61)	8.21 (5.77-10.99)	6.89 (4.21-10.50)	4.77 (2.92-7.88)
$CP_{average+}$	28.93 (21.61-38.79)	26.39 (20.36-32.49)	21.12 (17.07-25.32)	10.62 (7.65-14.41)	12.93 (9.39-16.70)

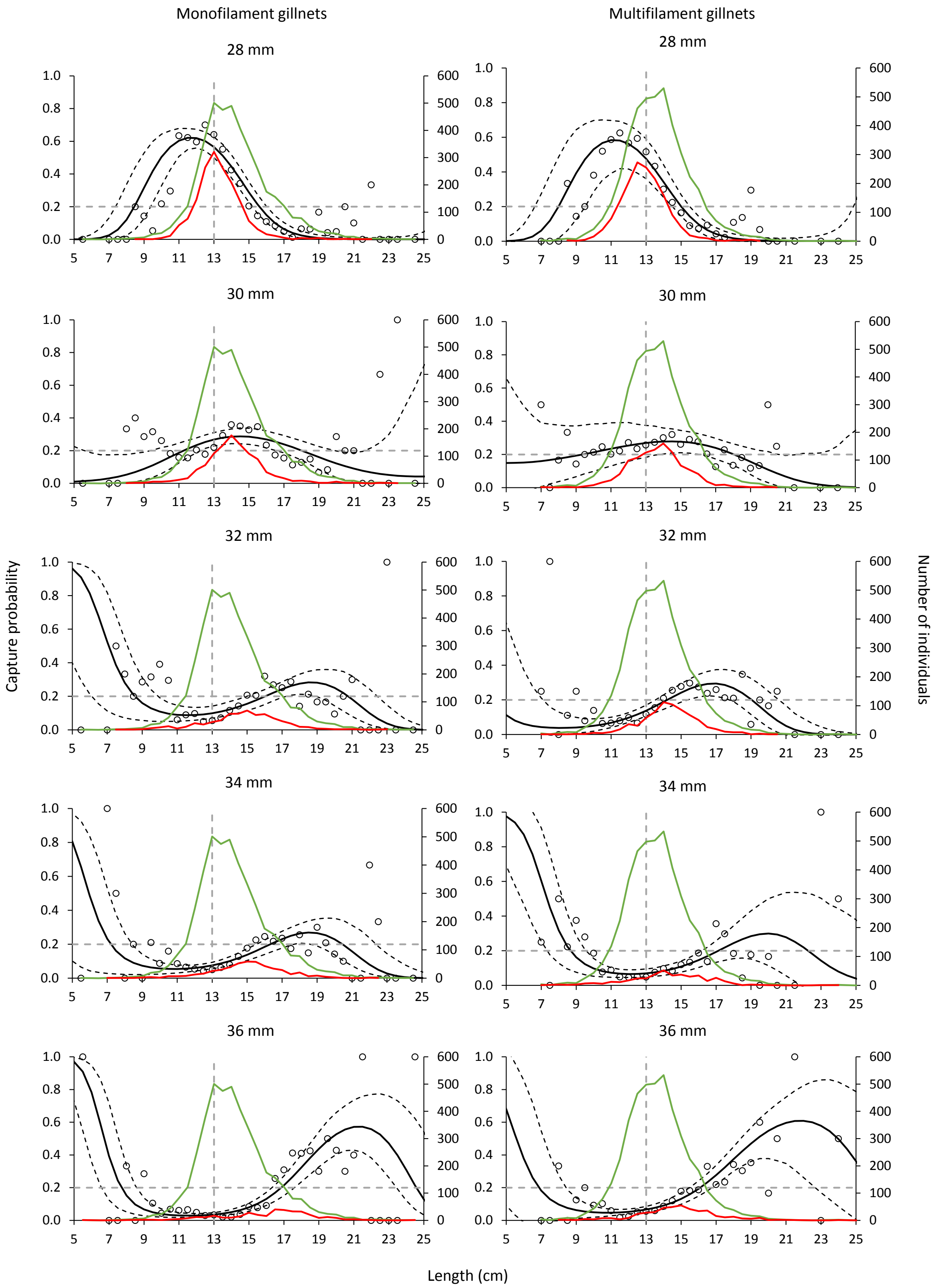
Monofilament gillnets
Multifilament gillnets
28 mm
30 mm
32 mm
34 mm
36 mm
Capture probability
Number of individuals
Length (cm)

Figure 3. Length-dependent capture probability of the five different gillnet mesh sizes (28, 30, 32, 34 and 36 mm) for whiting in monofilament (left) and multifilament (right) gillnets. In capture probability plots, circle marks represent experimental rates and black solid curves represent the modelled length-dependent capture probability. Stippled black curves represent 95% confidence intervals. Green solid lines are the summed captured population of the five mesh sizes while red solid lines represent captured population of the specific mesh size. Vertical dashed lines at 13 cm represent the minimum landing size for whiting in the Black Sea gillnet fishery. Horizontal dashed lines at 0.2 show the baseline for equal capture probability of gillnets of the five different mesh-sizes.

The pairwise differences (delta) in length-dependent capture probability between the five gillnet mesh sizes are shown in Fig. 4 and Fig. 5 for monofilament and multifilament gillnets, respectively. For monofilament gillnets, the results showed that netting with the smallest mesh size (M28) captured significantly larger amount of undersized whiting when compared to the other gillnets. Furthermore, M28 gillnets retained significantly less fish above the MLS compared to gillnets with larger mesh sizes (Fig. 4). Specifically, M30, M32, M34 and M36 gillnets had significantly higher capture probability for whiting above the MLS compared to small mesh size nets (Fig. 4). However, the pairwise differences between gillnets of larger mesh sizes regarding capture of undersized whiting were not statistically significant for all sizes of whiting (e.g., pairwise comparison between M32 and M34) or for some length classes (e.g., M32 and M36 and between M34 and M36). Similar results were also observed for multifilament gillnets with higher capture of undersized whiting and lower capture of whiting above the MLS in small mesh size multifilament nets (ML28) when compared to larger mesh size gillnets (Fig. 5).

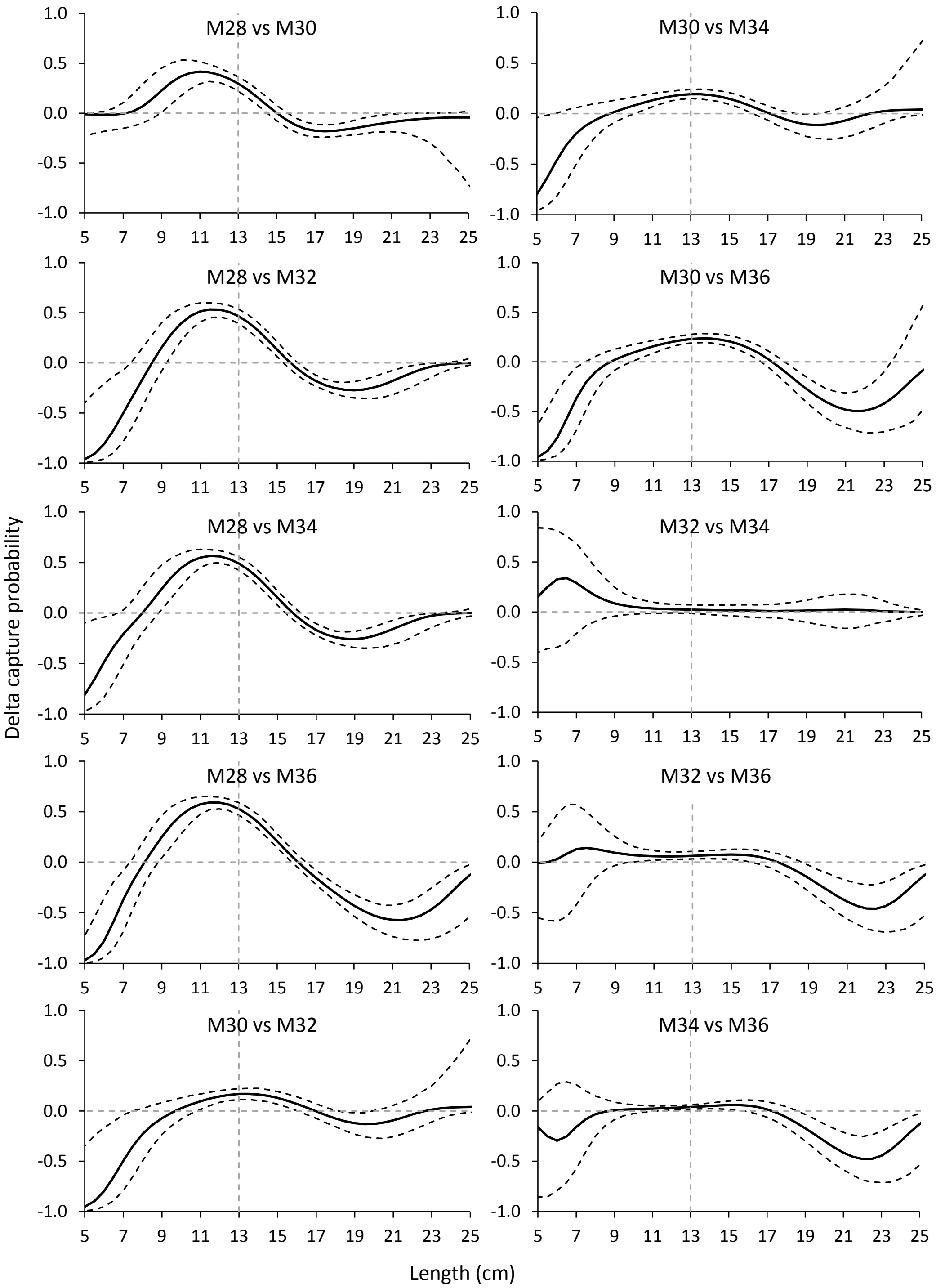

Figure 4. The pairwise difference in capture probability (delta) for monofilament gillnets between the five tested mesh sizes (M28, M30, M32, M34 and M36). In each comparison, the solid black curve represent the delta capture probability, and the stippled curves represent the 95% confidence intervals. Horizontal stippled lines at 0.0 show the baseline

of no significant difference between the compared mesh sizes. Vertical lines at 13 cm represent the minimum landing size for whiting.

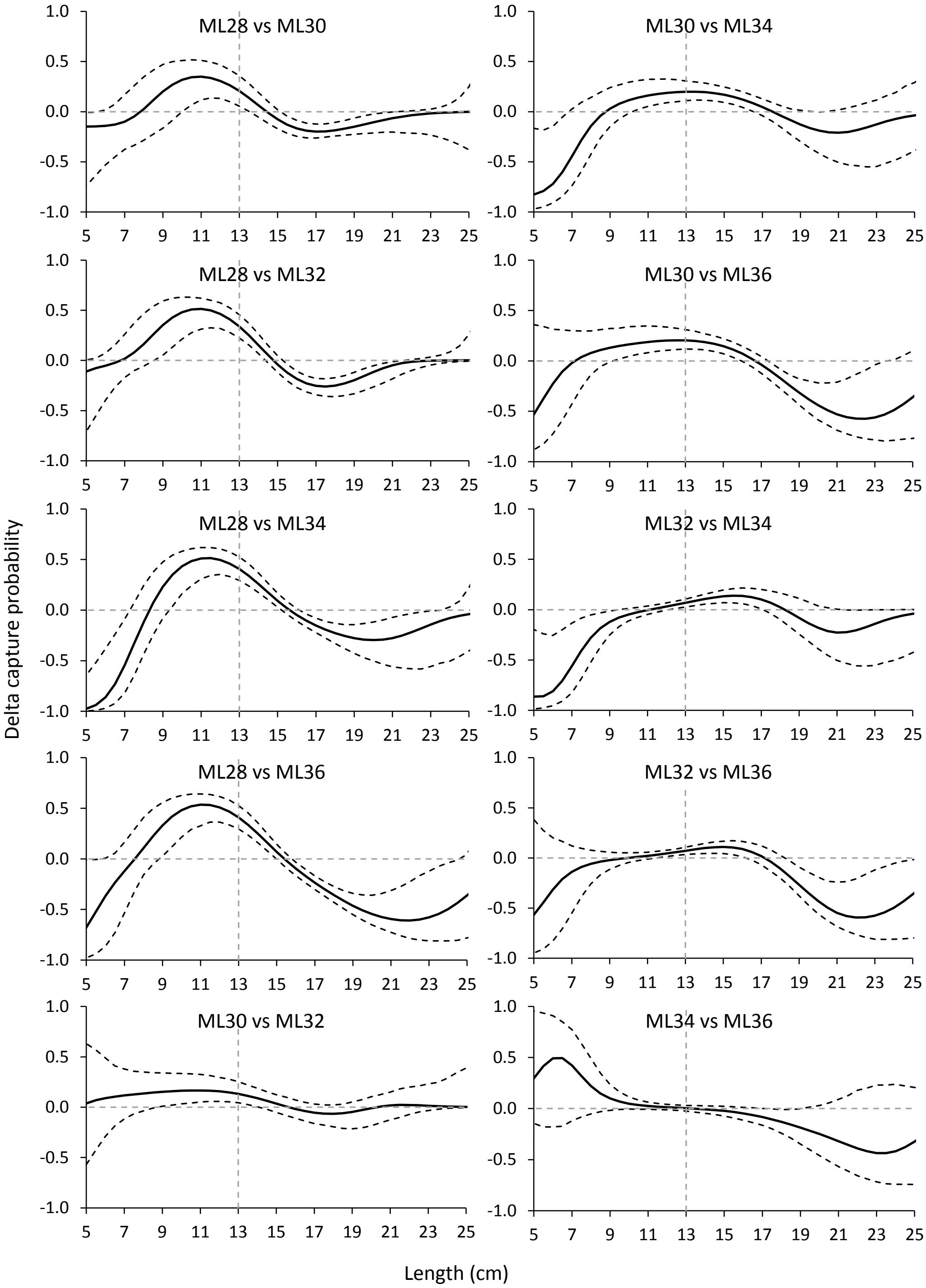

Figure 5. The pairwise difference in capture probability (delta) for multifilament gillnets between the five tested mesh sizes (ML28, ML30, ML32, ML34 and ML36). In each comparison, the solid black curve represent the delta capture probability, and the stippled curves represent the 95% confidence intervals. Horizontal stippled lines at 0.0 represent the baseline of no significant difference between the compared mesh sizes. Vertical lines at 13 cm represent the minimum landing size for whiting.

3.3 Catch efficiency between monofilament and multifilament gillnets

For catch comparisons between monofilament and multifilament gillnets of 30, 32 and 34 mm mesh sizes, the *p*-value was above 0.05, demonstrating that the model described the experimental data sufficiently well (Table 4). For gillnets of 28 and 36 mm mesh size the *p*-value was lower than 0.05. However, the catch comparison curve represented the trends in experimental data well (Fig. 6). Therefore, in those cases, the low *p*-value was assumed to be due to overdispersion in the data (Wileman et al., 1996).

The length-dependent catch comparison and catch ratio curves for gillnets with 28 – 34 mm mesh sizes showed no significant differences in catch efficiency between monofilament and multifilament nets for undersized whiting, as the 95% CIs included the baseline for equal catch efficiency. For 28, 32 and 36 mm mesh sizes, some differences in capture efficiency for some length classes of whiting over the MLS were shown with monofilament gillnets capturing more whiting compared to multifilament gillnets (Fig. 6). However, the length-integrated average catch ratio values for undersized ($CR_{average-}$) and target-sized whiting over the MLS ($CR_{average+}$) did not show significant differences in average catch ratio (Table 3).

Further, the differences in discard ratio values for monofilament ($wDiscard_{monofilament}$) and multifilament ($wDiscard_{multifilament}$) gillnets did not show any significant differences for any of the compared mesh sizes in the percentage of captured undersized whiting in weight. However, the discard ratio values differed between the different gillnet mesh size. Specifically, the discard ratio values ranged from 5 – 29% in monofilament gillnets and 7 – 40% in multifilament gillnets (Table 4). For both gillnet types, the discard ratio showed a decreasing rate when the netting mesh sizes were increased from 28 mm (Table 4).

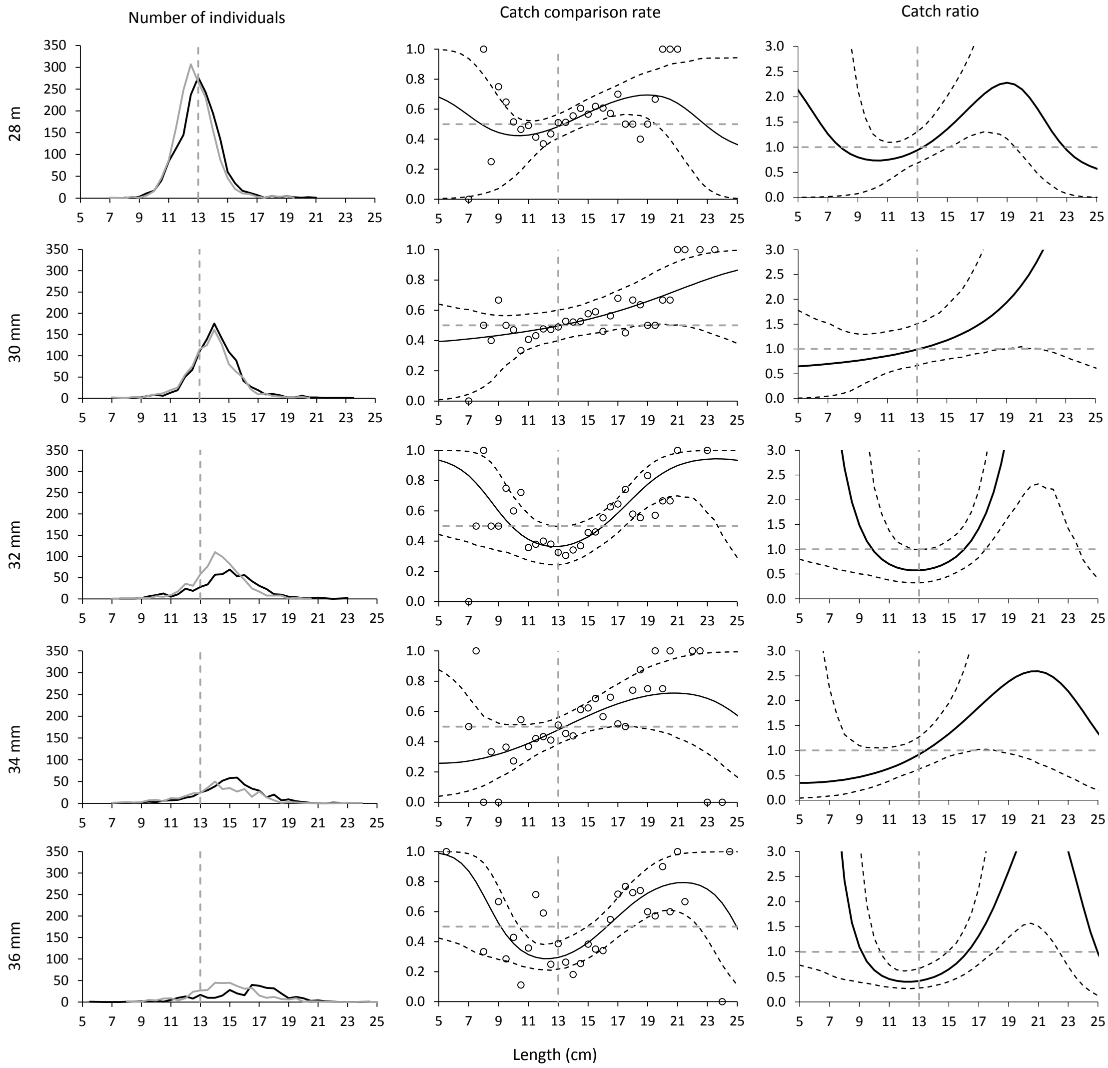

Figure 6. Catch comparison rates and catch ratios of the monofilament versus multifilament gillnets of different mesh sizes (28, 30, 32, 34 and 36 mm) for whiting. Left: number of whiting captured in monofilament (black) and multifilament (grey) gillnets of each of the five mesh sizes. Middle: the modelled catch comparison rates (solid black curves) with 95% confidence intervals (black stippled curves). Right: the estimated catch ratio (solid black curves) with 95% confidence intervals (black stippled curves).

Vertical lines at 13 cm represent the minimum landing size of whiting. Horizontal stippled lines at 0.5 and 1.0 for catch comparison rate and catch ratio plots, respectively, represent the baseline at which monofilament and multifilament gillnets have equal catch efficiency.

Table 4. Catch ratio (*CR*) and discard ratio (*wDiscard*) results (in %), and fit statistics of monofilament versus multifilament gillnets of five different mesh sizes for whiting. Values in parentheses represent 95% confidence intervals. DOF denotes degrees of freedom. *: values > 1000. - : no observations.

		28 mm	30 mm	32 mm	34 mm	36 mm
Length (cm)	5	-	-	-	-	* (73.40-*)
	6	-	-	-	-	* (65.49-*)
	7	126.24 (01.75-*)	69.63 (04.77-152.56)	497.4 (64.47-*)	37.51 (08.17-224.44)	669.33 (54.24-*)
	8	184.03 (00.73-644.82)	72.82 (10.28-137.16)	264.30 (56.76-*)	41.21 (12.47-131.84)	241.55 (44.62-*)
	9	96.05 (03.85-480.08)	76.54 (22.73-130.12)	148.64 (50.43-594.56)	46.63 (19.22-109.66)	109.64 (39.19-324.88)
	10	79.83 (07.62-213.22)	80.85 (37.75-130.74)	94.79 (44.90-225.67)	54.03 (27.45-105.40)	63.23 (34.47-127.26)
	11	74.75(32.88-109.65)	85.85 (51.93-135.75)	69.95 (37.44-137.27)	63.74 (38.64-105.70)	45.71 (29.21-74.11)
	12	81.56 (52.73-113.28)	91.73 (60.72-140.63)	59.40 (33.31-107.77)	76.18 (50.81-111.94)	40.27 (26.94-61.66)
	13	93.96 (68.48-130.85)	98.72 (66.62-150.94)	57.34 (31.98-99.13)	91.76 (62.72-127.01)	41.85 (27.78-66.43)
	14	121.13 (83.02-159.68)	107.14 (74.20-164.66)	62.24 (36.26-102.99)	110.80 (74.51-154.59)	49.63 (32.32-79.61)
	15	135.91 (98.24-201.35)	117.43 (78.97-187.11)	74.97 (45.82-118.70)	133.36 (88.09-194.87)	65.02 (40.52-102.15)
	16	164.02 (113.65-251.39)	130.19 (83.21-218.36)	99.03 (61.25-147.44)	159.02 (95.37-260.50)	90.97 (54.23-142.48)
	17	193.20 (126.64-316.87)	146.23 (90.50-270.65)	141.48 (83.40-218.05)	186.65 (102.06-359.69)	131.29 (75.31-226.55)
	18	217.43 (128.13-422.71)	166.68 (96.86-338.91)	215.69(121.46-388.99)	214.18 (100.82-519.14)	188.72 (99.15-406.01)
	19	227.74 (116.48-556.16)	193.10 (100.04-470.30)	345.04 (166.16-832.73)	238.38 (93.94-814.83)	260.70 (128.52-811.66)
	20	214.84 (84.10-733.34)	227.67 (104.42-718.44)	562.58 (209.55-*)	254.99 (86.26-*)	333.87 (153.50-*)
	21	177.74 (23.39-*)	273.27 (101.26-*)	891.04 (232.14-*)	259.27 (73.79-*)	381.69 (150.87-*)
	22	-	333.54 (94.31-*)	* (221.35-*)	247.45 (62.02-*)	373.85 (119.16-*)
	23	-	412.48 (83.46-*)	* (141.96-*)	218.98 (47.73-*)	300.36 (70.77-*)
	24	-	-	-	135.17 (19.95-*)	191.04 (32.50-*)
	25	-	-	-	-	97.11 (12.40-*)
	$CR_{average-}$	74.46 (48.03-109.49)	83.65 (59.85-129.81)	82.14 (47.79-156.94)	65.22 (38.63-120.00)	69.70 (43.21-107.14)
	$CR_{average+}$	118.09 (87.45-164.23)	115.19 (78.09-173.38)	80.99 (49.81-124.82)	139.94 (92.25-197.55)	89.86 (53.66-140.86)
	$wDiscard_{monofilament}$	28.85 (17.53-40.53)	9.54 (6.78-12.73)	7.19 (4.31-11.40)	5.48 (3.60-7.61)	4.63 (2.85-7.84)
	$wDiscard_{multifilament}$	40.15 (28.82-51.51)	12.89 (6.90-21.12)	8.69 (4.69-13.50)	11.39 (6.13-17.91)	7.33 (4.31-11.54)
	p-value	0.0235	0.8793	0.1482	0.0532	< 0.001
	Deviance	38.32	17.90	32.35	39.82	64.62
	DOF	23	26	25	27	26

4. Discussion

To the best of our knowledge, this study is the first to comprehensively quantify the capture efficiency in whiting gillnet fishery using two different netting twine constructions, mono- and multifilament twines, and five different mesh sizes for each construction. The main objective of this study was to compare catch efficiency in the Black Sea whiting gillnet fishery using commonly used gear configurations and to identify which twine construction and mesh size should be used for sustainable harvesting of whiting. Since the optimal gillnet configurations for this fishery have not been scientifically established, and due to the bycatch and discard issues of undersized whiting, the results of this study can serve as technical guidelines for improving the sustainable exploitation of whiting in this gillnet fishery.

Our results in this fishery demonstrate that increasing the mesh size in both, mono- and multifilament gillnets, can significantly improve the capture of whiting above the MLS of 13 cm while reducing the capture of undersized individuals, as reflected by length-dependent capture probability curves and delta capture probability curves. For example, when compared to the smallest mesh size gillnets of both mono- and multifilament nets, M28 and ML28, gillnets with larger mesh sizes showed lower capture probability for undersized whiting and higher capture probability for whiting ≥ MLS. Furthermore, this was also reflected by average capture probability values with lower $CP_{average-}$ and higher $CP_{average+}$ values for whiting below and above the MLS, respectively. These findings are consistent with the earlier studies targeting the same species of whiting using similar gillnets in the same region (Kalaycı and Yeşilçiçek, T., 2014a; Kalaycı and Yeşilçiçek, T., 2014b) as well as studies targeting different species with various gillnets in different regions around the world (dos Santos et al., 2003; Fonseca et al., 2005; Doll et al., 2014; Lucchetti et al., 2020). Specifically, gillnets are generally considered a size selective fishing gear (He, 2006; Savina et al., 2022); therefore, the capture probability of fish of different sizes in the gear can be alternated. As shown in these earlier studies, gillnet mesh size is one of the key parameters affecting the size of the target species that are retained in the gear with larger fish being retained in gillnets with an incresead mesh size (i.e., Lucchetti et al., 2020). Therefore, mesh size is an important factor affecting the catches of target and bycatch fish in gillnet fisheries (Kalaycı and Yeşilçiçek, 2014b; Soe et al., 2022).

In addition to mesh size, gillnet twine type can further have an effect on catch efficiency (i.e., Collins, 1979; He, 2006; Sala et al., 2018) due to, for example, potentially increased visibility of multifilament compared to monofilament netting (He, 2006) or differences in netting properties with netting made of monofilament being more rigid than multifilament twine (Stewart, 1978). Previous studies have tested the use of monofilament and multifilament net materials in different gillnet fisheries (e.g., Richardson and Flinn, 2019; Eighani et al., 2020) with varrying results. In particular, Richardson and Flinn (2019) revealed that multifilament gillnets had a three times more likelihood of capturing gar (*Lepisosteidae sp.*) compared to monofilament gillnets. In contrast, the research by Eighani et al. (2020) showed higher catch rates (up to 1.3 times) for *S. commerson* and other targetted species, such as mackerel tuna (*Euthynnus affinis*), as well as discarded species like giant catfish (*Netuma thalassina*), when monofilament gillnets were used in comparison to multifilament gillnets. The differences observed between these studies were attributed to species-specific catching mechanisms within the gillnet material.

In this study, monofilament gillnets showed an advantage over multifilament gillnets for the specific MLS of whiting. Specifically, for 28, 32, and 36 mm mesh sizes, monofilament gillnets captured more whiting over the MLS while for undersized whiting both twine configurations for 28-34 mm mesh sizes showed no significant difference in catches with an exception of the largest mesh size capturing fewer undersized whiting (between 11-13 cm).

However, the average catch ratios for undersized ($CR_{average-}$) and whiting over the MLS ($CR_{average+}$) demonstrated no significant differences. Furthermore, the percentage of captured undersized whiting (discard ratio) between monofilament and multifilament gillnets showed decrease in percentage of captured undersized whiting with larger mesh sizes starting from 28 mm. The reasons for the observed differences between the two gillnet configurations are unknown, and, as in earlier studies, can depend on both, the gear properties (rigidness or visibility in water) (He, 2006) or species-specific capture properties (Eighani et al., 2020) which require further observations. Specifically, fish of different species may be enmeshed differetly in mono- and multifilament nets, thus explaining the potential differences in capture efficiency. However, the results of this study suggest that in this whiting gillnet fishery in the Black Sea, the use of monofilament nets may be more useful for stock conservation and sustainable fishing compared to multifilament nets when considering the set MLS for this fishery.

Specification of MLS regulation is one of the main regulations by fisheries managment to protect Turkish fishery resources (TFR, 2020). Therefore, the fishing gear construction should correspond to such MLS regulations to enhance the capture of legally sized individuals while simultaneously minimizing the bycatch of undersized conspecifics. Currently the MLS for whiting is 13 cm according to Turkish fisheries legislations (TFR, 2020). However, the reported size at first sexual maturity for whiting varies, with Ismen (1995) and Samsun (2005) noting 12.5 cm and 12.9 cm for males and 14.7 cm and 13.8 cm for females, respectively. Ismen (1995) recommended a minimum catch size of 17.5 cm to reduce fishing pressure on whiting stocks. Genç et al. (1999) indicated that female whiting reach reproductive age at 2 years, which corresponds to an average length of 14.94 cm. Therefore, there is a significant difference between the size at which sexual maturity is reached and the length at which the fish are currently catchable. In the light of all these assessments, a more precautionary MLS for conservation and sustainability of the whiting stocks would be 15 cm (Kalaycı and Yeşilçiçek, 2014a). Based on the results observed in this study, the use of the smallest and largest mesh sizes, 28 mm and 36 mm, would not be optimal for targeting whiting in both monofilament and multifilament gillnets. Specifically, the 28 mm mesh size resulted in capture of a significant number of small whiting below the MLS, while gillnets with 36 mm mesh size showed a reduced capture probability for commercially desired whiting above the MLS. However, it is observed that in the study area, the mesh size of gillnets for whiting fishing has been reduced from the previous 40 to 44 mm down to 28 mm over the years (Aydın, 1997; Genç et al., 2002). Kalaycı and Yeşilçiçek (2014a) have pointed out that the reduction in mesh size over the years could be attributed to fishermen's efforts to increase their catch due to decrease in catches of large individuals. This may lead to high fishing pressure on the stock over time.

When the considering the findings of the present study with previous research on gillnets and first maturity length of whiting in the region, it can be recommended that in this Black Sea whiting gillnet fishing, 32 or 34 mm mesh size netting, preferably monofilament gillnets, are used for the conservation of whiting stocks. This is in line with the present regulations determining the MMS in monofilament gillnets in the region (TFR, 2020). However, since multifilament gillnets are also commonly used in this fishery, similar MMS regulations could be beneficial for fisheries sustainability. Further research and considerations of the practical implications of these findings are essential for the development of effective fisheries management strategies in the region. Furthermore, more studies assessing the effect of gear design changes on the catch composition in this fishery are necessary to consider not only the target species but also species caught in this fishery.

CrediT authorship contribution statement

Cemil Altuntaş: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization. **Adnan Tokaç:** Supervision, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing - original draft. **Bent Herrmann:** Formal analysis, Methodology, Software; Supervision, Validation, Writing - original draft. **Devrim Selim Mısır:** Data curation, Formal analysis, Investigation. **Murat Dağtekin:** Conceptualization, Funding acquisition, Project administration, Data curation. **Kristine Cerbule:** Formal analysis, Methodology, Validation, Visualization, Writing - original draft.

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.

Data availability

Data will be made available on request.

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