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RESEARCH PAPER

Selectivity of Different Alternative Cod Ends and Radial Square Mesh Escape Panels (RSEP)

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Abstract

Bottom trawl fishery is carried out intensively throughout the season in the Black sea. For this reason, the selectivity effects of five codend with different mesh size, shapes and escape panels (commercial (40D), 50 mm diamond-shaped (50D), and 40 mm square-mesh (40S) and radial square mesh escape panels (RSEP) which were added to the front and back section of 40D) were investigated. Using a commercial fishing trawl, 44 valid hauls were carried out from August 23rd to October 24th 2016 on the Sakarya coast to the South west of the Black Sea. The L_{50} value of commercial cod end was calculated as was 12.9 cm for *Mullus barbatus* (red mullet), and was improved in cod ends with RSEPs. Further, the L_{50} values obtained from the other cod ends were found to be very high (40S: 15.62 cm, 50D: 15.24 cm). It was noticed that none of the cod ends showed sufficient selectivity for bluefish (*Pomatomus saltatrix*), which was caught as bycatch. The comparative account of the findings of current study with the previous studies advocates that the cod ends need to be made from PA netting and RSEP should be applied for more escape area.

Introduction

Bottom trawl fishery in the Black Sea is extensively carried out during the fishing season by 521 trawlers that are capable of bottom trawl fishing (Anonymous, 2018). In bottom trawl fishery, main target species are *Mullus spp*. and whiting (*Merlangius merlangus*). The mesh size and shape of codend were determined as 40 mm diamond and, this regulation will be changed to 44 mm at the beginning of the 2020 fishing season (Anonymous, 2016). There are no any standardizations (size, mesh number of perimeter i.e.) in related to codend. In addition, it is known that fishermen have applied many illegal methods, such as using double and lower mesh size codends (Ceylan, Şahin & Kalaycı, 2014; Ceylan and Sedef pers.com.). *Mullus spp.* is the target species preferred by fishermen and a very large part of total production (96%) obtained from bottom trawl fishery (Knudsen, Zengin, & Koçak, 2010). It has been reported that decreasing of marketable size of red mullet indicates that its stock was under pressure due to over fishing (Zengin *et al.,* 2014). Another problem of trawl fisheries in the Black Sea is illegal fishing carried out with small fishing boats called as pirates in the banned season (from 15 April to 31 August) (Küçük, Sedef and Doğu Pers. com.). Illegal fishing in the same period as the breeding season of many fishes threatens their sustainability. Total production of striped red mullet (*M. surmuletus*) and Red mullet (*Mullus barbatus*) species has been reported as 2708.8 tons in the Black Sea, but some researchers reported that the *M. surmuletus* is absent in the Black Sea (Anonymous, 2018; Keskin, 2012; Akdemir, 2015). Although *M. surmuletus* reaches the

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sexual maturity at more length, its minimum landing size MLS (11 cm) differs from *M barbatus (13 cm)* (Anonymous, 2016). The definitions of these mullets vary in the literature and there is terminological confusion in Turkish identification of both species (Akdemir, 2015). As a result, there are major lacks that need to be regulated in terms of the management of *M. barbatus* stocks in the Black Sea.

Bottom trawl fishery in Turkish seas has a multispecies character, so that some pelagic species are caught as bycatch by bottom trawlers in the Black Sea. Bluefish (*Pomatomus saltatrix*) is commonly targeted in purse seine fishery but it is one of the most caught species as bycatch by bottom trawlers at the beginning of the fishing season mostly in September and October (Ceylan, Şahin & Kalaycı, 2014; Özdemir, Erdem, Erdem & Özdemir, 2014; Yıldız & Karakulak, 2017). The MLS of blue fish was 20 cm before 2016 while it was currently defined as 18 cm in the Turkish fisheries circular covering the fishing seasons between 2016 and 2020. (Anonymous, 2016). The commercial codend doesn't exhibit sufficient selectivity for this species. If a regulation is made to reduce the bycatch ratio of blue fish, the losses of dominant target species must be taken into account in the trawl fishery (Özdemir *et al*., 2014). Therefore, it should be considered that a positive effect cannot be obtained at the same time for each species when a modification is made.

Recent studies have been conducted the effects of different types of net materials, the number of mesh around the codends, escape panels, mesh size, and the shape on the selectivity were evaluated (Broadhurst & Kennelly, 1996; Chen, Matuda & Honda 1991; Petrakis & Stergiou, 1997; Tokaç, Özbilgin & Tosunoğlu, 2004). It has been reported that various shapes and sizes of the mesh exhibit adverse effects on fishes with different body shape and swimming ability (Tosunoğlu, Aydın & Özaydın, 2008). The square-mesh nets ensure superior selectivity and have become more popular owing to their ability to protect their shape during the haul. Nevertheless, it has not been well adopted by fishermen due to the shift of knots and subsequent difficulty in repairing (Graham & Kynoch, 2001). Therefore, several studies have been carried out to increase the selectivity by applying square mesh panels to a certain portion of the codend (Armstrong, Briggs & Rihan, 1998; Broadhurst & Kennelly, 1996; Özbilgin, Tosunoğlu, Aydın, Kaykaç & Tokaç, 2005). In general, the panels placed in the upper and the front portions of the codends have shown positive effects on selectivity (Graham, Kynoch & Fryer, 2003; Metin *et al.,* 2005). Despite positive results, the top panel combinations developed for different species have sometimes been reported to be inadequate (Brcic, Herrman, & Sala, 2016; Santos, Herrman, Otero, Fernandez & Perez, 2016). Commercial codend with square mesh escape panel could not be obtained sufficient selectivity value for both red mullet and blue fish (Metin *et al*., 2005; Özdemir *et al.,* 2014). European Commission required fishermen have to use 40 mm square mesh or 50 mm diamond mesh codends in GFCM areas (E.C, 2006). Therefore, it's important to be known the selectivity characteristics of these codends in the Black Sea. Due to the continuous advancements in the technology, development of novel and superior net materials, and efforts to increase the selectivity, abundant scientific explorations have been carried out in different periods in bottom trawl nets with a low selectivity feature.

The aim of the current study was to determine more selective alternative codends for bottom trawls used in the Black Sea. In this context the present study was conducted to investigate the selectivity effects of the radial square escape panel (RSEP) added to the front and rear portions of the commercial codend by expanding the square-mesh panel area, which offers a potential alternative to the commercial trawl codend, which is usually aimed at small size fish. In addition, the selectivity characteristics of 40 mm commercial codend 50 mm diamond-shaped codend and 40 mm square-mesh codend manufactured from polyamide (PA) material were also assessed.

Materials and Methods

A total of 61 trawling operations were carried out on the Sakarya coast of the South West Black Sea from August 23 to October 24, 2016, by participating in 22-day fishery activities of a commercial trawler (LOA: 14,95 m, 380 HP) (Figure 1). The study involved in the 700-mesh bottom trawl net that is commercially used for fishing activities. The selectivity data were recorded for 44 valid hauls with a total time of 52 hours. The *M. barbatus* was the target fish species in all operations. Data were collected at the depth ranging from 20 to 50 m, 45–85 minutes of haul time and 2.6 –3.5 knots of haul speed. During the operations, the captain's preferences related to depth, speed, and duration were not interfered. The funnel part of the net was made from 300 mesh (44 mm) polyethylene (PE) material and the commercial codend was made from PA material with 40 mm mesh opening (40D), 200 perimeter mesh and about 6 m length. The protected net was made up of polypropylene material with a mesh size of 80 mm in 3.5 mm thickness and had a width of 55 and a length of 160 meshes. Other codends used are as follows: 50 mm diamond (50D), 40 mm square (40S) and 40 mm RSEP (50 mesh) added on the front (RSEP*f*: 80 cm after the funnel) and rear (RSEP*r*: 80 cm before the end of the codend) of the 40D were shown in Figure 2. When the RSEPs were netted, a mesh was added in a bar. The thickness (210d/18), length and number of perimeters of all codends were the same as 40D. The mean mesh size of all codends was measured using OMEGA mesh gauge by applying 50-N force (Table 1.) (Fonteyne,

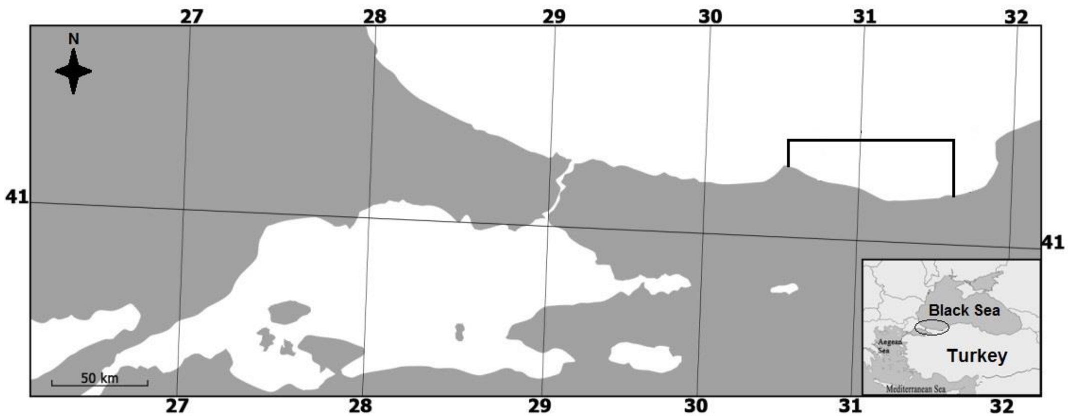

Figure 1. The study area.

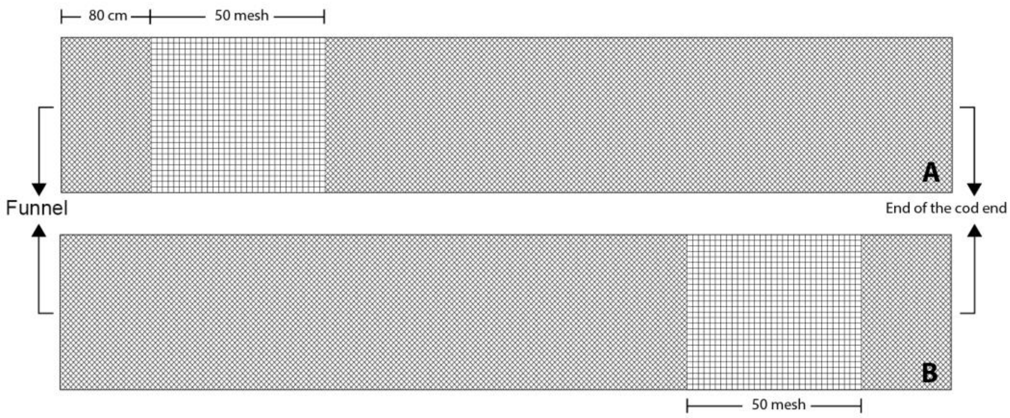

Figure 2. The codends which square mesh escape rings (A: RSEP*f*, B:RSEP*r*) added.

Table 1. The mean mesh sizes of used nets after samplings

Net materials	40D	40S	50D
Mesh size	40	40	50
Measured mesh size	42.34	41.87	51.51
SE	1.26	1.38	0.95
N	60	60	60
Min.- Max. (mm)	37-45	34-44	49-53
Material	PA	PA	PA

Buglioni, Leonori, O'Neill, & Fryer, 2007). The cover was made from 24 mm PA material and was supported by two circles of 1.2 m in diameter (Wileman, Ferro, Fonteyne & Millar, 1996; Tosunoğlu, Tokaç, Lök, & Metin, 1997). The catch, which accumulates in the cover and the test codend, was dumped separately to the deck and the fish were measured nearest cm accuracy. The selectivity parameters of each haul for *M. barbatus* as well as *P. saltatrix* were estimated by fitting a logistic function:

$$r(l) = \exp\left(v_{1+v_2} l\right) / [1 + \exp(v_1 + v_2 l)]$$

$$L_{50} = \frac{-v_1}{v_2}$$

Where *r(l)* is retained proportion of length class and *v* : parameters to be estimated (Wileman *et al.,* 1996).

The data were analyzed using maximum-likelihood method using CC2000 software (ConStat, 1995). The mean L_{50} value (50% retention length) for each codend was calculated by between-haul variation method developed by Fryer (1991) and the effects of RSEPs on the L_{50} were estimated with ECModel software. The L_{50} value of each codend for *P. saltatrix* was calculated as pooled data because required number of prey were not caught at each haul. A likelihood ratio test was performed to evaluate statistically differences between selection curves of blue fish obtained from codends (McCullagh & Nelder, 1991).

Results

During the study, a total of 44 valid hauls were carried out with the tested codends from 40D to 10, 50D to 6, 40S to 9, RSEP*f* to 10 and RSEP*r* to 9. The details of the hauls, the total amount of catches obtained in the cover and the test codend are summarized in Table 2. The total catch volume in the cover ranged between 22.5–267.63 kg, while in the tested codends it ranged between 15–114.67 kg. About 10 valid hauls were carried out with the 40D at a depth between 20 and 55 m. The minimum and maximum haul speeds were 2.6 and 3.5 knots, respectively. The total time of hauls was 545 min and duration of each hauls varied from 45 to 60 min. The total catch in cover and 40D codend were 956.7 kg and 679.9 kg, respectively. A total of 31458 red mullets and 12176 bluefish were caught throughout the sampling. The calculated L_{50} and SR values for red mullet and bluefish were 12.98 cm and 2.83 cm, and 13.67 and 2.40 cm, respectively. Six valid hauls were conducted with the 50D at a depth ranging from 40 to 45 m. The minimum and maximum towing speeds were 3.2 and 3.5 knots, respectively. The total towing time was 335 min and haul durations varied from 45 to 70 min. During the sampling, the total catch volume was 826.7 kg in the

Table 2. The details of valid hauls performed in the sampling area

Type	Date	Speed (Knot)	Depth (m)	Time Start	End	D. (min)	CC (kg)	cc (kg)
40D								
1	23.08.2016	2.6	30-55	06:55	07:45	50	112	15
2	23.08.2016	2.6	20-55	06:35	07:25	50	114.8	22
3	24.08.2016	3	34-36	09:30	10:30	60	101	94.6
4	24.08.2016	3	36	11:50	12:50	60	98	97.22
5	25.08.2016	3.5	33	06:00	07:00	60	112.5	86
6	25.08.2016	3.5	30-32	08:00	08:45	45	78.5	39.1
7	25.08.2016	3.4	33	09:35	10:35	60	108.63	83.8
8	25.08.2016	3.2	34	11:00	12:00	60	73.25	86.1
9	25.08.2016	3.2	35	12:35	13:35	60	169.5	82.13
10	25.08.2016	3.2	38	17:55	18:35	40	101	73.9
50D								
1	02.09.2016	3.3	40	06:54	07:30	45	98.6	70.7
2	02.09.2016	3.2	40	08:00	08:45	45	94.4	68.7
3	02.09.2016	3.3	45	09:00	10:10	70	189.5	81.5
4	02.09.2016	3.4	41-44	10:30	11:40	70	170	19.4
5	02.09.2016	3.3	40	12:00	13:10	70	170.3	25.5
6	02.09.2016	3.4	40	13:40	14:25	45	134.28	46.6
40S								
1	3.9.2016	3.5	32	07:15	08:15	60	98.65	33.2
2	4.9.2019	3.3	22	07:00	08:00	60	22.5	39.5
3	5.9.2016	3.3	41	07:30	08:30	60	146.9	36.8
4	5.9.2016	3.5	50	09:45	10:30	45	220.5	42.1
5	5.9.2016	3.2	41	10:45	12:00	75	133.5	25
6	5.9.2016	3.2	41	12:25	13.45	80	219.2	66
7	5.9.2016	3.2	41	14:10	15:10	60	181.1	39.2
8	9.9.2016	3.2	39	07:15	08:25	70	96.6	40.3
9	9.9.2016	3.2	33	08:45	09:50	65	50.25	49.46
RSEP*f*								
1	14.9.2016	3.3	24-25	10:40	11:50	70	141.3	41.2
2	14.9.2016	3.3	24	12:10	13:25	75	91.13	66.9
3	14.9.2016	3.3	23-28	13:50	15:15	85	88.2	81.82
4	14.9.2016	3.3	27-28	17:40	18:50	70	62.5	44.54
5	15.9.2016	3.2	25	08:50	09:50	60	27.85	32.9
6	15.9.2016	3.2	27-28	07:30	08:30	60	42.5	46.1
7	15.09.2016	3.2	33-36	11:30	12:30	60	227	28.9
8	15.9.2016	3.2	36	10:10	11:10	60	266.79	48.1
9	15.9.2016	32	32-35	13:00	14:00	60	267.63	62.5
10	15.9.2016	3.3	24	15:10	16:25	75	190.8	55.5
RSEP*r*								
1	15.09.2016	3.3	24-26	13:00	14:10	70	138	51.5
2	16.09.2016	3.2	26-28	06:50	07:50	60	176.6	114.67
3	16.09.2016	3.2	26-28	08:15	09:20	65	181.5	119
4	20.10.2016	3.4	49	06:45	07:55	70	58.14	25.35
5	20.10.2016	3.5	33-54	11:05	12:30	85	36.61	39.1
6	21.10.2016	3.4	48-50	14:10	15:10	60	77.5	33.9
7	21.10.2016	3.4	49	08:45	09:45	60	71.5	31.6
8	21.10.2016	3.5	35-55	10:20	11:40	80	38.98	36.9
9	24.10.2016	3.4	52	06:55	08:15	80	66.81	22.83

(CC: Total cod end catch; cc: Total cover catch; D: duration).

cover and 306.2 kg in the codends. A total of 33265 red mullets and 7397 blue fish were caught. The calculated L_{50} and SR values for red mullet and blue fish were 15.24 and 2.71 cm, and 16.39 and 4 cm, respectively.

About 9 valid hauls were made with 40S at 40-45 m of depth. The minimum and maximum towing speeds were recorded as 3.1 and 3.5 knots, respectively. The total towing time was 715 min with haul duration between 45–80 min. During the sampling, the total catch volume was 1568.2 kg in cover and 460.3 kg in the codends. In total 27847 red mullets and 5239 bluefish were caught in the hauls. The calculated L_{50} and SR values for red mullets and bluefish were 15.62 and 2.91 cm, and 16.9 and 3.17 cm, respectively. With RSEP*f*, 10 valid hauls were made at depth of 23–36 m. The minimum and maximum towing speeds recorded were 3.2 and 3.3 knots, respectively. The total towing time was 745 min with haul duration varying between 60–85 min. During the sampling, the total catch volume was 1573.9 kg in the cover and 566.6 kg was in the test codend. With RSEP*f*, a total of 79584 red mullets and 10567 bluefish were caught. The calculated L_{50} and SR values for red mullet and bluefish were 14.66 and 2.92 cm, and 14.98 and 2.89 cm, respectively. Likewise, with the RSEP*r*, 9 valid hauls were made at the depth between 24–55 m. The towing speed varied from 3.1 to 3.5 knots. The total towing time was 710 min with haul duration varying from 60 to 85 min. The total catch volume in the cover and the codend was 1001 and 519.3 kg, respectively. A total of 30001 red mullets and 1316 bluefish were caught. The calculated L_{50} and SR values for red mullet were 13.83 and 3.93 cm, while 14.3 and 2.5 cm for bluefish. The selectivity curves for *M. barbatus* and *P. saltatrix* are shown in Figure 3 and 4. It was found that the RSEPs significantly affect the L_{50} (P<0.05). The

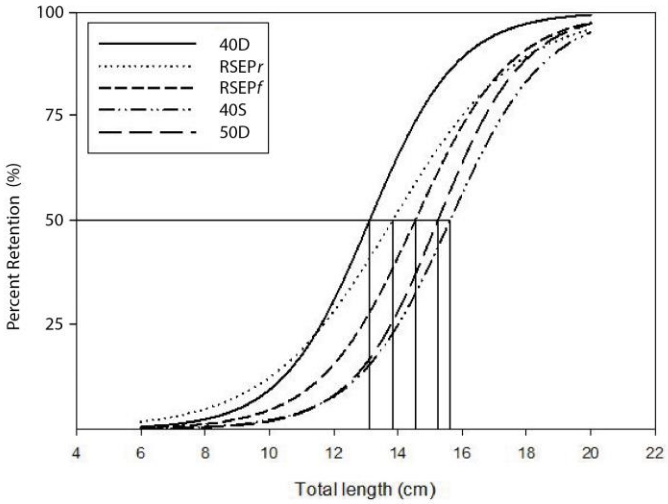

Figure 3. Selectivity curves of *M. barbatus.*

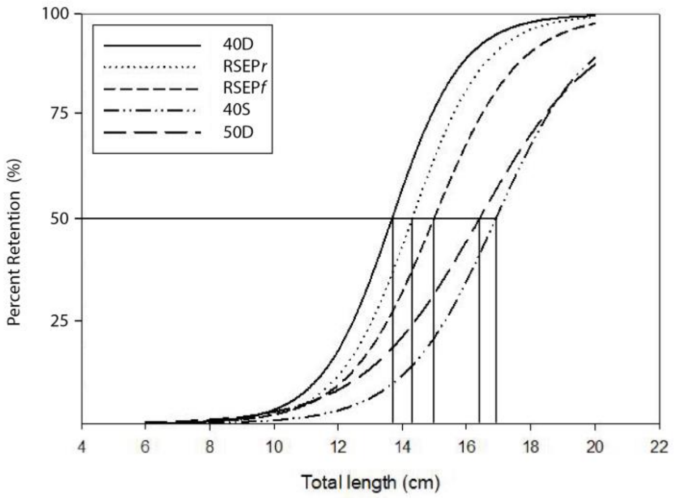

Figure 4. Selectivity curves of *P. saltatrix.*

calculated selectivity and regression parameters with their standard errors, matrix values of each haul and mean curves are shown in Table 3. Size frequencies of *M. barbatus* and *P. saltatrix* caught in the cover and tested codends are given Figure 5.

Selection curves of all the codends (50D, 40S, RSEP*f* and RSEP*r*) were compared to 40D and significant differences were found ($p<0.05$)

Table 3. Selectivity parameters for all hauls

40D	L_{50}	SE	SR	SE	SF	V_1	V_2	R_{i11}	R_{i12}	R_{i22}	Deviance
M. barbatus											
1	11.99	0.15	2.99	0.49	3.0	–8.802	0.734	2.0682	-0.1758	0.0150	70.79
2	14.22	0.25	2.92	0.33	3.6	–10.683	0.751	1.1251	-0.0900	0.0073	19.35
3	12.91	0.37	3.66	0.83	3.2	–7.738	0.599	2.5709	-0.2162	0.0184	143.63
4	13.71	0.12	2.12	0.15	3.4	–14.164	1.033	0.8868	-0.0720	0.0059	8.81
5	13.60	0.52	3.67	0.82	3.4	–8.135	0.598	2.4639	-0.2098	0.0181	131.8
6	12.95	0.14	2.60	0.22	3.2	–10.945	0.845	0.7680	-0.0648	0.0055	27.15
7	13.86	0.38	2.53	0.26	3.5	–12.032	0.868	0.9855	-0.0876	0.0081	25.65
8	13.25	0.92	5.40	1.37	3.3	–5.383	0.406	1.0769	-0.1058	0.0106	62.8
9	12.02	0.14	3.33	0.48	3.0	–7.934	0.66	1.2794	-0.1093	0.0094	36.28
10	12.89	0.27	3.29	0.55	3.2	–8.604	0.667	1.7587	-0.1478	0.0126	98.32
Mean (Fryer)	12.98	0.24	2.83	0.175	3.2	–9.530	0.734				
P. saltatrix (pooled)	13.67	0.076	2.40	0.15	3.7	–12.47	0.912	0.6053	-0.0441	0.0032	80.69
50D											
1	14.82	0.81	3.83	0.91	3.0	–8.492	0.573	2.6635	-0.2225	0.0189	90.08
2	14.25	0.41	2.55	0.34	2.9	–12.255	0.860	1.7527	-0.1516	0.0133	41.85
3	16.48	0.73	3.02	0.48	3.3	–11.986	0.727	2.0785	-0.1676	0.0137	31.57
4	15.20	0.56	3.13	0.48	3.0	–10.644	0.700	1.7034	-0.1407	0.0118	69.42
5	17.10	0.44	3.25	0.31	3.4	–11.561	0.676	0.6887	-0.0531	0.0042	20.56
6	14.47	0.32	2.16	0.27	2.9	–14.661	1.013	2.55885	-0.2053	0.2053	97.59
Mean (Fryer)	15.24	0.543	2.71	0.206	3.0	–11.450	0.751				
P. saltatrix (pooled)	16.39	0.218	4.00	0.343	3.2	–8.985	0.548	9.5487	-0.6775	0.0484	74.19
40S											
1	14.91	0.38	2.95	0.35	3.7	–11.083	0.743	1.1489	-0.0936	0.0078	40.27
2	14.93	0.99	7.32	2.32	3.7	–4.481	0.300	1.3297	-0.1090	0.0090	13.39
3	15.71	0.53	2.63	0.45	3.9	–13.125	0.835	3.5562	-0.2691	0.0207	94.87
4	15.78	0.42	2.91	0.37	3.9	–11.904	0.754	1.6056	-0.1203	0.0092	89.89
5	16.77	0.45	3.26	0.37	4.2	–11.288	0.673	1.0245	-0.0767	0.0058	35.25
6	16.36	0.74	3.13	0.55	4.1	–11.471	0.701	2.4721	-0.1946	0.0156	125.18
7	15.49	0.33	2.47	0.25	3.9	–13.757	0.888	1.3018	-0.1023	0.0082	50.04
8	16.03	0.85	3.54	0.65	4.0	–9.927	0.619	1.7619	-0.1493	0.0129	43.83
9	13.77	0.39	3.02	0.54	3.4	–10.002	0.726	2.4525	-0.2015	0.0168	100.54
Mean (Fryer)	15.62	0.37	2.91	0.15	3.8	–10.608	0.679				
P. saltatrix (pooled)	16.90	0.43	3.17	0.64	4.2	–11.701	0.692	4.6782	-0.3034	0.0198	41.22
RSEP*f*											
1	13.46	0.32	2.24	0.28	3.4	–13.187	0.979	1.9764	-0.1728	0.0153	164.90
2	15.75	0.56	3.39	0.48	3.9	–10.210	0.648	1.2615	-0,1024	0.0084	170.63
3	15.60	0.77	4.13	0.82	3.9	–8.303	0.532	1.6527	-0.1346	0.0112	352.20
4	15.32	0.69	3.55	0.62	3.8	–9.486	0.619	1.6462	-0.1393	0.0119	95.70
5	16.64	0.93	4.14	0.79	4.2	–8.837	0.531	1.5022	-0.1245	0.0104	31.00
6	15.76	0.76	5.47	0.88	3.9	–6.323	0.401	0.5321	-0.0467	0.0042	35.82
7	14.57	0.34	2.60	0.28	3.6	–12.284	0.843	1.1849	-0.1003	0.0086	72.75
8	12.79	0.26	2.12	0.29	3.2	–13.229	1.034	2.613	-0.2297	0.0204	43.76
9	15.70	1.65	7.19	3.04	3.9	–4.806	0.306	2.4846	-0.2021	0.0167	76.14
10	13.81	0.27	2.62	0.25	3.5	–11.563	0.837	0.8322	-0.0725	0.0064	21.22
Mean (Fryer)	14.66	0.36	2.92	0.23	3.6	–9.742	0.664				
P. saltatrix (pooled)	14.98	0.25	2.89	0.45	3.7	–11.372	0.759	2.7867	-0.1964	0.0140	353.67
RSEP*r*											
1	13.74	0.56	5.30	1.14	3.4	–5.690	0.414	1.1346	-0.0941	0.0080	54.29
2	12.25	0.40	3.56	0.66	3.1	–8.168	0.616	1.9217	-0.1584	0.0133	26.58
3	14.24	0.48	4.97	0.95	3.6	–6.280	0.441	1.1800	-0.0905	0.0071	25.72
4	14.82	0.78	4.65	1.02	3.7	–6.181	0.806	1.5924	-0.1292	0.0108	73.84
5	14.07	0.48	5.08	0.88	3.5	–6.080	0.432	0.7804	-0.0661	0.0057	163.70
6	13.51	0.37	4.70	0.73	3.4	–6.311	0.467	0.7467	-0.0622	0.0053	36.63
7	14.03	0.45	4.98	0.82	3.5	–6.188	0.441	0.7461	-0.0630	0.0054	163.64
8	14.15	0.25	2.94	0.29	3.5	–10.576	0.747	0.7900	-0.0651	0.0054	18.50
9	13.05	0.33	3.08	0.53	3.3	–9.305	0.713	2.160	-0.1789	0.0151	47.53
Mean (Fryer)	13.83	0.16	3.93	0.32	3.4	–7.070	0.511				
P. saltatrix (pooled)	14.30	0.08	2.50	0.135	3.5	–12.557	0.879	0.4816	–0.0328	0.0023	12.02

L_{50} SR (Selection range), SF (Selectivity factor), SE (Standard error) are the selectivity Parameters. V_1 and V_2: maximum likelihood estimators of the selectivity parameters. R_i. are values in the covariance matrix.

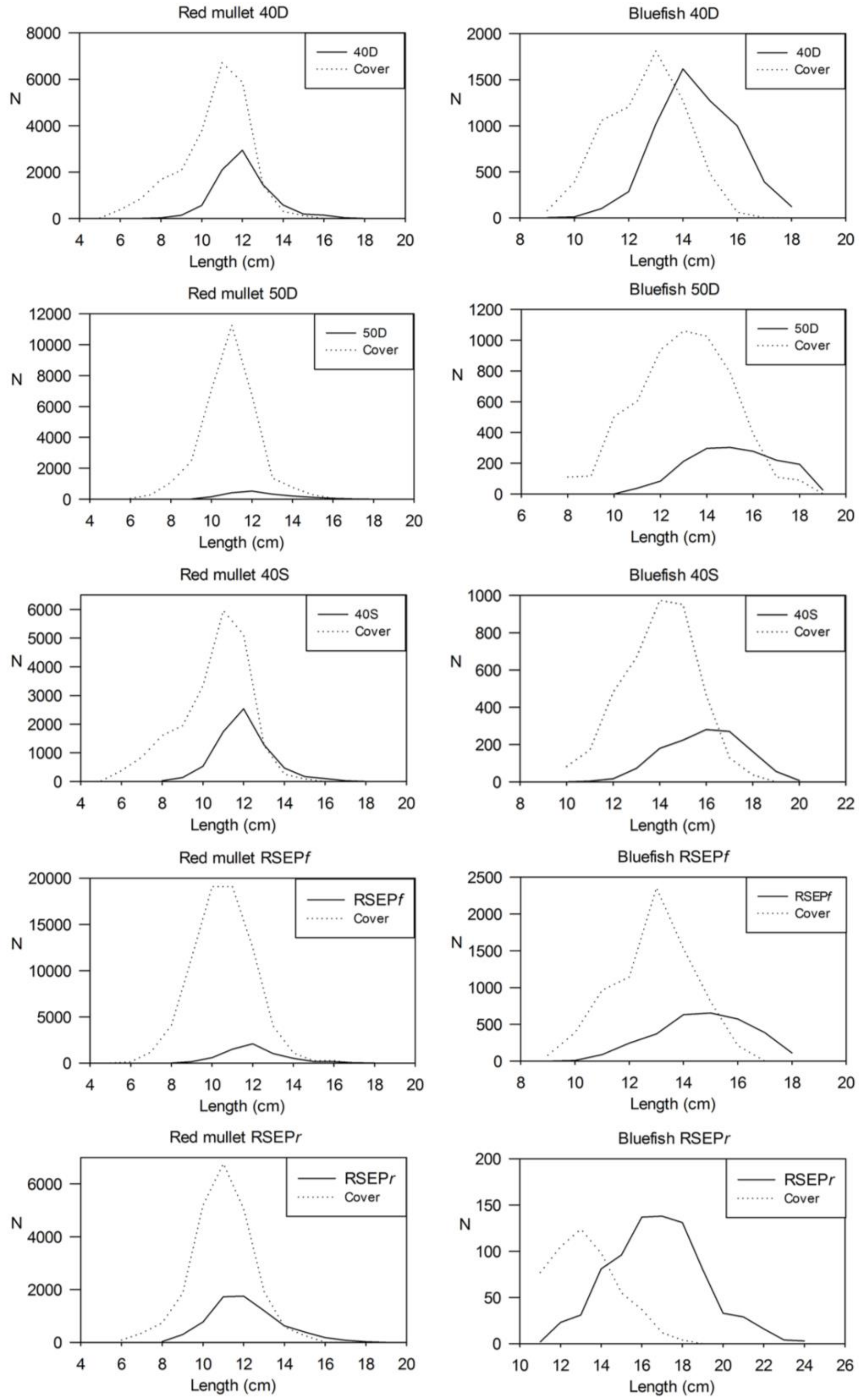

Figure 5. Size frequencies of *M. barbatus* and *P. saltatrix* caught in the cover and tested codends.

Discussion

When the explorations carried out in the Black Sea were thoroughly examined, it is clearly understood that the whiting, red mullet and turbot are the most targeted species, and the horse mackerel and the bluefish are caught as non-target or bycatch by bottom trawl (Ceylan, Şahin & Kalaycı, 2014; Özdemir, Erdem & Erdem, 2012; Zengin, Genç & Tabak, 1997). In the communique issued by the Ministry of Food, Agriculture, and Livestock, Turkey (MoFAL), which regulates commercial fishery, the minimum landing size (MLS) of *M. barbatus* is 13 cm. The data obtained from the studies related to the length at first maturity size

Table 4. Some studies related to the length at first maturity size for *Mullus barbatus*

Reference	Region	Length (cm)
Arslan and İşmen (2013).	Aegean Sea	♂ 12.1 cm, ♀ 11.9 cm
Cherif, Zarrad, Gharbi and Jarboui (2007).	Mediterranean Sea	♂ 13.87 cm, ♀ 13.94 cm
Tursi,Matarrese, D'onghia and Sion (1994).	Mediterranean Sea	♂ 12.5 cm, ♀ 13.5 cm
Akyol, Tosuboğlu and Tokaç (2000).	Aegean Sea	* 12.9 cm (fork length)
Carbonara et al. (2015).	Mediterranean Sea	♂ 10.1 cm, ♀ 12.1 cm
Genç, (2000).	Black Sea	♂ 10,17 cm, ♀ 11.28 cm
Kokokiris, Stamoulis, Monokrousos and Doulgeraki, (2014).	Aegean Sea	♀ 11.4 cm
Fabi et al. (2002).	Adriatic Sea	* 11 cm

* includes all individuals without sex discrimination

for *M. barbatus* in different regions are given in Table 4. The L_{50} value of 40D (L_{50}: 12.98 cm) was found acceptable value for the MLS specified, although taking into account the length at first maturity size obtained from previous studies, it still shows partial selectivity characteristics in catching the fish on the first maturity size.

The L_{50} value calculated in the current study is very similar to that obtained previously for *M. barbatus* using the same net material, and codends of similar mesh shape and size in the Black Sea (Zengin *et al.,* 1997, Genç, 2000). On the contrary, it was reported that L_{50} values were below the first maturity size as well as the MLS in experiments where the codends were made from PE material, having the same characteristics in terms of codend circumference, mesh size and shape (Tokaç *et al*., 2004; Özbilgin, Tosunoğlu, Tokaç & Metin, 2011; Kaykaç, Zengin & Tosunoğlu, 2018). Many researchers have reported that the type of material used for manufacturing the codend also affects the selectivity and PA nets have a superior selectivity than PE nets (Akyol, Tosunoğlu & Tokaç, 2000; Deval, Bök, Ateş & Özbilgin, 2006; Tokaç *et al.,* 2004). The PA material has a more flexible structure and is suitable for taking the body shape and thereby allows the easy escape of a fish (Tokaç *et al.,* 2004). The PA net material used in the study can be considered as the reason why the L_{50} value is higher than some studies reported from other regions. In recent times, PE nets with less selectivity seem to be preferred by fisherman due to their robustness and durability. Given the fact that PA nets with the same mesh size give better selectivity results, only nets in the codend section should necessarily be made from PA material. The L_{50} value (15.24 cm) obtained with 50D was above the first maturity size as well as the MLS. In a different study conducted in the Aegean Sea, the circumference of mesh was 264, and the L_{50} value for *M. barbatus* was reported as 12.9 cm with 50 mm diamond-shaped codend of PE material (Dereli & Aydın, 2016). This could be attributed to the use of PE nets and the adverse effects of the number of the circumference on selectivity (Deval *et al*., 2006; Sala, Priour & Herrmann, 2006; Tokaç *et al*., 2004). In another study carried out in the Aegean Sea, 50 mm diamond-shaped codend (PE) was reported to have no positive effect on the same level for all species. At the same time, they obtained more effective results on the horse mackerel because of its body size and swimming ability (Tosunoğlu, Aydın & Özaydın, 2008). It is inevitable that the use of 50D codend will positively contribute to the species selectivity, but it may also adversely affect the caught biomass of small fishes targeted such as whiting and red mullet. The use of 50D can help in increasing the selectivity of the size of high-bodied bycatch species such as bluefish, and shad etc. However, the total biomass of red mullet, the main targeted species will be negatively affected. Therefore, fishermen would not accept this codend as an economically viable gear. There are available several reports endorsing the superior selectivity of square-mesh codend over the diamond-shaped codend (Bahamon, Sarda & Suuronen, 2006, Dereli & Aydın, 2016, Özbilgin *et al*., 2015, Petrakis & Stergiou, 1997). The L_{50} value (15.62 cm) of 40S for red mullet is much above the MLS as well as the first maturity size and it is almost similar to that of 50D. It is presumed that fishermen will experience economic losses in short and long term due to the low retention rate of 40S. Using square mesh codends instead of commercial codend brings about 40% much more economic losses (Eryaşar & Özbilgin, 2015). They are also concerned that commercial losses may not be voluntary in using codend, which is entirely consisted of square meshes. It is well known that the slipping of knots and further difficulty in repairing square-mesh nets are also not much appreciated by fishermen (Metin *et al.,* 2005). However, it was seen in this study that square-mesh nets hanging at a 45-degree angle could be repaired in the same way as diamond nets. Sometimes, it is not possible to achieve the consistent positive effect for each species in the bottom trawling with the same codend, especially when the fishes with different body shapes and behaviors are caught together by alone enlarging the mesh size or using square mesh, so that when a codend is designed, nets consisting of both square and diamond-shaped mesh must be used together (Metin *et al*., 2005; Petrakis & Stergiou, 1997, Tosunoğlu, Özbilgin & Özbilgin, 2003a, b). It may also allow the escape of different species that might be caught unintentionally. Previously, there have been reported positive effects on the selectivity of square-mesh escape panels in different studies conducted in many regions (Graham & Kynoch, 2001; Graham, Kynoch & Fryer, 2003; Metin *et al*., 2005; Özdemir *et al.,* 2012; Özdemir, Erdem, Erdem & Özdemir, 2014; Queirolo *et al.,* 2008). In this study, instead of adding any panel, RSEPs completely surrounding the back and front of 40D codend were used taking account of capturing the different behavior and body shaped fish. The L_{50} value of the 40D below the MLS was notably improved. The L_{50} values of the RSEPs may likely to vary and this difference might be due to the fact that the codend knot and biomass that accumulates in the codend affects the mesh-opening of RSEP*r*. In order to conserve the stocks for a sustainable fishery, there is a great need to improve the selectivity of the trawler. The L_{50} values of *M. barbatus* obtained in 50D (15.24 cm) and 40S (15.62 cm) were beyond the MLS as well as the first maturity size. Prima facie, stocks are very important for maintaining the sustainability, but they may not offer an advantage in terms of full use of stocks. The modifications of the commercial codend with RSEP*f* and RSEP*r* would provide positive contributions toward the sustainability of fish stocks as well as yields because the L_{50} values of RSEP*f* (14.66 cm) and RSEP*r* (13.83 cm) were found at higher with the MLS in both the configurations. Because of the L_{50} value of RSEP*r* is closer to MLS, the use of RSEP*r* is recommended for a sustainable fishery. Özdemir *et al*., (2014) investigated the selectivity of bluefish caught as bycatch in the Middle Black Sea. They reported that square mesh panels were placed on the top and both sides of the codend, and only one panel placing on the codend was not enough to increase the size selectivity and the square panel spreading over a wider area would give better effects. As an alternative to 40D, all of the L_{50} values obtained for the bluefish from other tested codends (40D: 13.67, 50D: 16.39, 40S: 16.90, RSEP*f*: 14.98 and RSEP*r*: 14.30 cm) were increased but none was found above the MLS (Figure 4.). In the present study, the use of RSEP*f* exhibited a positive effect on the selectivity.

In addition, it would have favorable effects on selectivity of target and bycatch species in the multi-species fishing areas. However, the fact that the used codends remain below the permissible size limit for the L_{50} of bluefish suggests that different measures should be taken with new studies to be done for this species. It has been observed that fishermen use different legally inappropriate codends in the Black Sea, despite the fact that the bottom trawlers have to use a codend with the mesh size of 40 mm (Ceylan *et al.,* 2014). Considering that fishermen are able to get an advance notice of the inspection at sea; it is very important that the measures taken by the authorities are acceptable and practicable by the fishermen. The achievement of L_{50} value on the RSEP*r* codends and the minimum landing size (13 cm) suggest that fishermen should at least use this amendment for the sustainability of stock and fishery. For this reason, it is indispensable to review the communique regulating fisheries for the Black Sea. However, only the technical measures written in a directive are not enough to protect the ecosystem. It is necessary to have strict surveillance. The site and time-related inspections can be carried out online, however, the fishing activity done on the boat and their compliance with the law can only be checked on board. Often, priority should be given to standardization of the fishing gear used by unrestrained fishermen, according to the ecosystem approach, not the commercial affairs. Therefore, it is essential to apply the scientific outcomes and the revisions to contribute to the superior selectivity. The selectivity characteristics of fishing gear should be improved and fishermen should be encouraged to use these gears depending upon the region and the target species.

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