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Research Article Araştırma Makalesi

Selectivity Characteristics of the Sorting Grid in Shrimp Beam Trawls used to Reduce Bycatch in the Sea of Marmara

Marmara Denizi'nde Kullanılan Karides Algarnasında Hedeflenmeyen Türleri Azaltmak İçin Kullanılan Izgara Panellerin Seçicilik Özellikleri

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Abstract: Considerable by-catch problems have occurred in the commercial beam trawl fishery targeted at deep water pink shrimp in the Sea of Marmara. In this study, the grid systems were used to reduce the untargeted catch and improve the species' selectivity. By-catch reduction ratios of the beam trawls deployed with and without the grid were compared by the parallel hauling method. Selectivity values of 20 mm bar spacing grid and 24 mm mesh size cod-end were also analyzed by SELNET program. In general, by-catch reduction ratios of the grid beam trawl were determined as 50.6% and 56.9% in terms of number and weight, respectively. The reduction of target catch (*Parapenaus longirostris*) in the same gear was found to 23.1% in terms of number and 23.2% in terms of weight. In the model for rose shrimp, obtained according to the lowest AIC value, the selectivity parameters of the grid for L_{50} were 13.51 cm and for SR 4.76 cm. Selectivity parameters of the same species for 24 mm mesh size cod-end were; L_{50} = 8.99 cm and SR = 5.56 cm. These results indicated that grid usage benefits and contribute to sustainable fishery in the target catch-oriented fishing applications.

Keywords

- Deep water rose shrimp
- Beam trawl
- Target catch
- By-catch
- Grid

Özet: Marmara Denizi'nde derin su pembe karides avcılığında önemli derecede yan av sorunu yaşanmaktadır. Bu çalışmada hedef türün haricinde istenmeyen tülerin avcılığını azaltmak için ızgara panel sistemleri kullanılmıştır. Izgara panel sistemi yerleştirilen ve ızgara panel sistemi olmayan algarna takımlarının yan av yakalama oranları paralel çekme yöntemi ile karşılaştırılmıştır. 20 mm çubuk aralığı ızgarası ve 24 mm ağ göz açıklığına sahip torba seçicilik değerleri de SELNET programı ile analiz edilmiştir. Genel olarak ızgara panel kullanılan algarna takımının yan av azaltma oranları sayı ve ağırlık bakımından sırasıyla %50,6 ve %56,9 olarak belirlenmiştir. Hedef avın (*Parapenaeus longirostris*) azalması sayı olarak %23,1, ağırlık bakımından ise %23,2 olarak bulunmuştur. En düşük AIC değerine göre elde edilen derin su pembe karides modelinde ızgaranın seçicilik parametreleri L_{50} için 13,51 cm ve SR için 4,76 cm'dir. Aynı türün 24 mm ağ gözü açıklığındaki seçicilik parametreleri; L_{50} = 8,99 cm ve GD = 5,56 cm'dir. Bu sonuçlar, hedef av odaklı balıkçılık uygulamalarında ızgara panel kullanımının sürdürülebilir balıkçılığa fayda sağladığını ve etkili olduğunu göstermiştir.

Anahtar kelimeler

- Derin su pembe karidesi
- Algarna
- Hedef av
- Yan av
- Izgara panel

1. INTRODUCTION

Deep water rose shrimp (*Parapenaeus longirostris*, rose shrimp hereafter) is the predominant species in the benthic fauna of the Sea of Marmara (Zengin et al., 2004). Among the Turkish Seas, most of the shrimp landing (72%) has been supplied from the Sea of Marmara. In the last five decades, the average landing was 1590.8 (40.2-6236) tons. The sixty-three percent of rose shrimp export originated from the Marmara region. The commercial fishery of the shrimp has been carried out by traditional gears; bottom trawls (illegally) and beam trawls (locally named as "*algarna*"). While one vessel-operated beam trawls were used in the 1970s, the use of multi-gears (range between 2 and 5 beam trawl) have become widespread in the 1990s due to increasing commercial importance and increasing demand for rose shrimp.

The highest discard and incidental catch ratios in the world fisheries belong to shrimp-targeted bottom trawls (Hall, 1996). Discard and by-catch problems are seriously important where the species diversity is rich (Martin, 1992). In recent years, studies regarding shrimp trawls focused on excluder and separator panel designs for other species that share the same habitat and are being captured together with shrimps. Therefore, many studies were conducted on the selective grid trawl nets with different modifications which can provide optimum selectivity and eliminate other species (Isaksen et al., 1992; Klima, 1993; Graham, 1995; Tokai et al., 1990; Boulos & Brothers, 1996; Waldemarsen, 1996; Larsen, 1996; Madsen et al., 1999; Salini et al., 2000; Ye et al., 2000; Machias et al., 2001; Fonteyne & Polet, 2002; Graham, 2003). On the contrary, the number of studies conducted in Turkey is scarce (Aydın & Tosunoğlu, 2012; Özvarol, 2016). Usage of the leading panels and selective grids, a relatively new system for trawl fishery, was firstly performed in 1989 during coastal shrimp fishery for excluding jellyfish in Norway. Nowadays the purposes of grid applications in trawl fishery are improving species and size selectivity, eliminating untargeted species especially the turtles (*Caretta spp.*) during fishing operations, and increasing survival ratios of the escaping fish from the net (Larsen, 1996; Valdemarsen, 1996).

Fishers have operated with bottom trawl gears intensively since the beginning of the 1990s to obtain more yield and catch the shrimp stocks easily generally located between the depths of 100-200 m (Zengin et al., 2004). Bottom trawling has been completely prohibited since the early 1970s to protect demersal fish stocks in the Sea of Marmara. However, the failure in operating an effective control mechanism due to administrative, legal, and infrastructural deficiencies has been one of the most important reasons for persistent trawling in the area. High levels of by-catch and discard were reported in bottom trawl and beam trawl fisheries, especially for flatfish and cartilaginous fishes (Zengin et al., 2014; Zengin et al., 2017).

Shrimp landings in the Sea of Marmara within the last half century (1967-2019) show that shrimp catch has increased since the early 1980s and the production peaked in 1989 with 8380 tons. However, the number of landings started to decrease gradually in the following years and the number of catches decreased to 1200 tons in the 2010s. It is obvious that besides high fishing power, characteristics of traditional beam trawl nets also play a role in this decrease. On the other hand, destructed habitats caused by bottom trawling, which was applied for capturing deep water rose shrimp together with other macrofauna distributed over the benthic and benthopelagic zone and is completely prohibited for this sea, also have an important impact (Zengin et al., 2004; Zengin & Akyol, 2009).

This research aimed to reduce the ratio of bycatch shrimp catch taken by beam trawls and to increase the survival chance of commercial and non-commercial species in the Marmara Sea, which is subjected to the multi-species fishery. Studies related to the reduction of bycatch in the multi-species fishery all over the world are of great concern. Especially in trawling gear, various modification techniques towards the separation are available (Isaksen et al., 1992; Larsen, 1996; Broadhurst, 2000; Campos & Fonseca, 2000; Eayrs, 2007). With these motivations, modification studies have been carried out to reduce discard and non-target catch rates in traditional beam trawls, which are widely used for the rational sustainability of rose shrimp stocks in the Sea of Marmara.

2. MATERIAL AND METHODS

2.1. Study area

This study was conducted in five stations, İstanbul-Yeşilköy, İstanbul-Tuzla, Tekirdağ-Barbaros, representing Northern Marmara, and Erdek-Çakılköy, Gemlik Gulf, representing South Marmara (Figure 1) between August and September 2004. Water depth varied between 44 to 110 m, generally 50 to 80 m. Experimental surveys were carried out by commercial fishing vessels. In the sampling, vessels with a length of 9 to 12 m, and an engine power of 28 to 135 hp was used. The speed ranged from 1.5 to 1.8 knots.

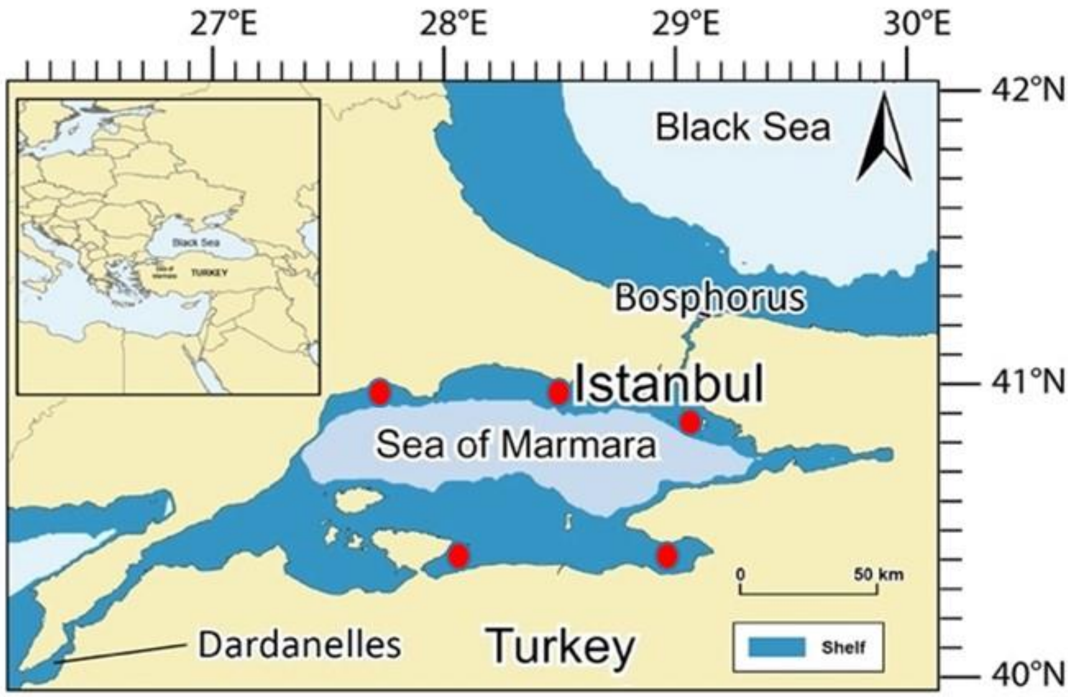

Figure 1. Map of the study area and sampling stations

To reflect the real situation, haulings were taken during the commercial fishing period. The average duration of these hauls was 3.8 (3.5-4) hours, although it varied locally. It has been reported that the rose shrimp was associated with feeding dynamics, light and dark rhythms of the day affect fishing and in general large amounts of prey were obtained during the day (Kangas et al., 2015). Similarly, operations in this study were performed during daylight.

2.2. Structural features of traditional beam trawl net

Beam trawl gears are composed of 5 components; net, beam, sledge, chain, and rope. The mouth opening of the net is as long as the beam. The length and height of the beam are generally 5-6 m and 50-60 cm, respectively, and are made of galvanized profile pipe (Figure 2). The total length of beam trawl nets is 11 m. A protective bag is generally placed over the cod-end; 2.5 mm twine diameter, Polypropylene (PP) 80 mm mesh size, and 2.5 strokes in length. Tow ropes connect the net to the vessel. Net release and tow are carried out by ropes via pulleys and cranes.

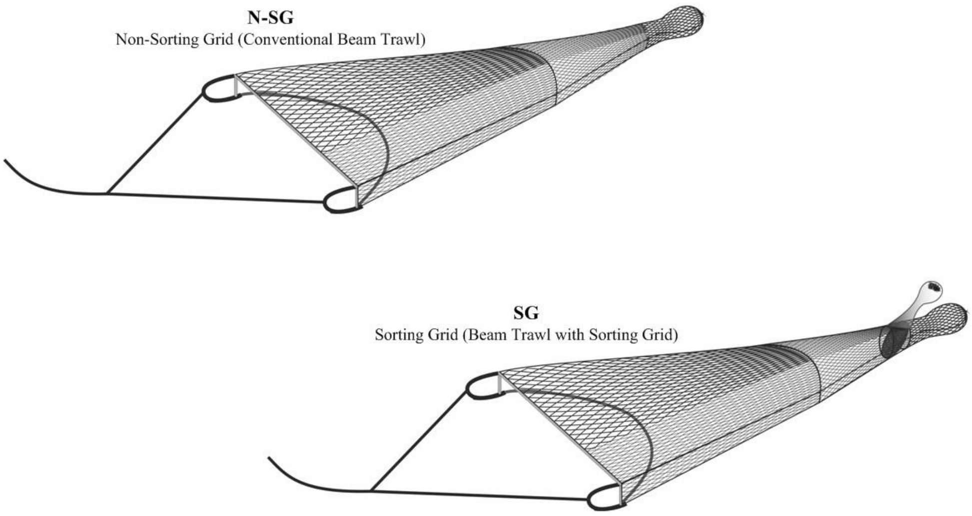

Figure 2. The beam trawls featured for shrimp used in the study (N-SG: Non-Sorting Grid, SG; Sorting Grid).

2.3. Designing the separator grid

The grid as presented in Figure 3 was formed by combining 31 chrome bars of 4 mm diameter with 20 mm bar spacing (Figure 3). The length and width of the ellipsoid panel given in Figure 3 were 108 and 77 cm, respectively. Bar spacing was determined according to the body height of the carapace zone of the target species rose shrimp in the present study. The panel was reinforced with crossbars from three equidistant points. The optimum operation angle of the grid was reported to be 45º (Isaksen et al., 1992). The perimeter of the grid panel was covered with a 6 mm mesh size (PA 210d/8) net of 403 meshes with a length of 74 meshes. An escape window was formed on this net which had a base of 49 and a depth of 24 meshes. For determining the escape species, a collective bag was also equipped to the mouth of the window.

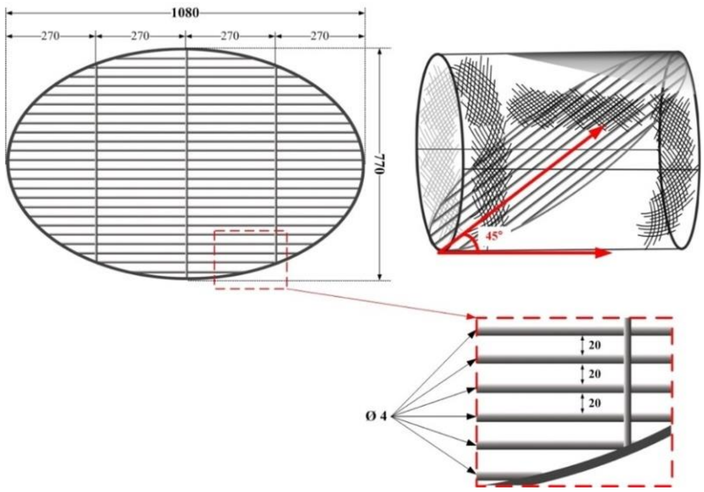

Figure 3. The sorting grid details and the positioning of the escape window (dimensions in this design are in mm)

2.4. Experimental studies

Two same-size beam trawls were used in the study; the first one without a grid panel and the second one with a grid panel mounted in front of the cod-end (Figure 2). A parallel hauling method was performed for comparing the selectivity and target catch ratio of the grid panel. In addition, the optimum catch length for the shrimp population was determined by using a 24 mm diamond mesh size to determine the selectivity in the bag part of the SG beam trawl (Figure 4). A grid cover of 24 mm mesh size was used for determining the excluded species by the grid. The shrimp catch of each haul was recorded and 1000-1500 g subsamples were separately taken from cod-end and cover. These subsamples were fixed in 10% formaldehyde solution for length measurement and transferred to the laboratory.

The hooped-covered cod-end method was used to collect selectivity data (Wileman et al., 1996) and benthic material from the nets. An 8.2 m longhand 12 mm mesh size knotless PA (polyamide) netting cover was used to collect the escaped individuals from the cod-end. The cover was supported by two hoops (PVC Ø 1.6 m) to avoid the masking effect and to provide water flow between the cod-end and the cover. These hoops were mounted on the cover at distances of 2.2 and 5.2 meters from the attachment point at the end of the funnel (Figure 4).

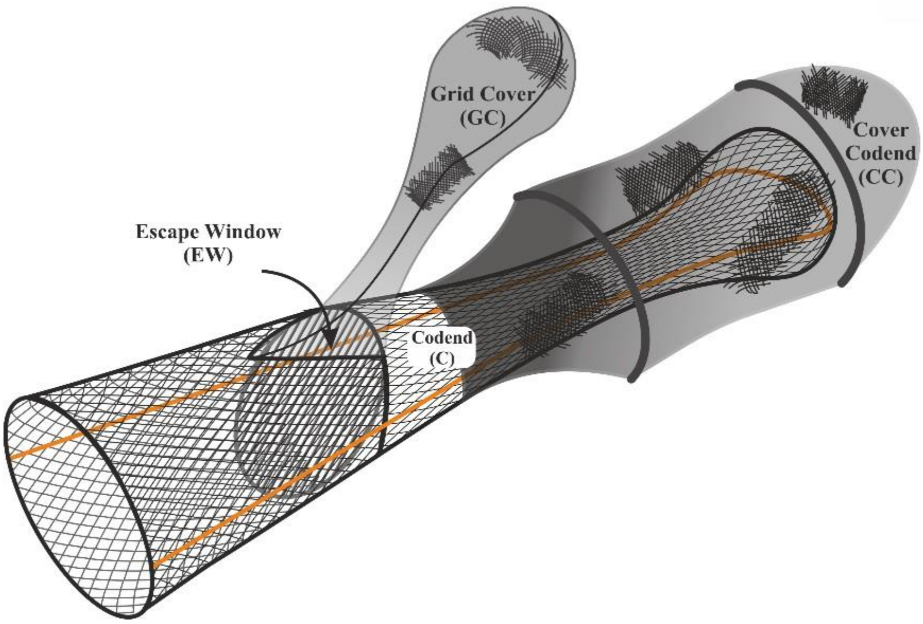

Figure 4. Positioning the sorting grid on the beam trawl cod-end (C: Cod-end; CC: Cover Cod-end; GC; Grid Cover; EW: Escape Window).

The total catch in the cover cod-end of the traditional and modified net and the total catch in the cod-end of the escape window were evaluated separately during sampling surveys. After the identification of the target catch and by-catch at the species level in both parts of the net, catch amounts of each species in terms of number and weight were recorded to datasheets.

2.5. Data analysis

Catches taken from traditional (control gear) and modified gears were taxonomically identified at the species level. Every Catch was recorded by number and weight. Target species (*P. longirostris*) and some important commercial fishes (hake, whiting, gurnard, sole) were measured to assess the total length (cm) frequency distribution. The catch per unit effort (CPUE) is used as an index for finding the bycatch reduction amount/ratio for both traditional and modified gear.

CPUE was used to determine the catch difference of beam trawl hauls. The catch of each trawl operation was standardized. Calculated CPUE in such a case shows the change of catch related to fishing effort (Phiri & Shirakihara, 1999). CPUE was calculated by the following formulae, CPUE=(∑C/Nç)/(∑T/Nç); CPUE; fishing index (kg/h), C; catch amount of each target catch (kg), T; sampling time (h), Nç; the number of hauls.

2.6. Selectivity analysis

The size selection is termed as a sequential dual selection system in the beam trawl cod-end comprised of two main phases. These were 20 mm bar spacing grid selectivity and a 28 mm diamond mesh cod-end selectivity (Figure 4). The first selection process started when the rose shrimp and fish encounter the rigid sorting grid, after that the second process followed the first one was completed. Fish and invertebrates that did not pass through the grid accumulated in the top cover of the grid compartment. Specimens that passed through the grid enter the size-selective cod-end, where the second selection process occurs. In order to be retained in the cod-end (rcombined (*l*)), every individual has to be retained by the first (rgrid(*l*)) and the second process (rcodend(*l*)): rcombined(*l*) = rgrid(l) × rcodend(*l*) where *l* denotes the length of the individuals. The selectivity analyses procedures performed in this study are similar to those previously implemented by Sistiaga et al. (2010), Herrmann et al. (2013), and Brcic et al. (2015). According to these studies, the probability of fish passing through the grid for fish that make contact with it can be modeled with the following log it model:

$$\text{rcontact}(l, \text{L50grid}, \text{SRgrid}) = 1 - \log \text{it}(l, \text{L50grid}, \text{SRgrid}) \text{ where:}$$
$$\log \text{it}(l, \text{L50}, \text{SR}) = \exp(\ln(9) \times (l - \text{L50})/\text{SR})\ 1 + \exp(\ln(9) \times (l - \text{L50})/\text{SR})$$

The model involves pooling the haul data. To account for the increased uncertainty in the estimation resulting from subsampling, a double bootstrap method was used to estimate 95% Efron percentile confidence intervals (Efron, 1982; Chernick, 2007) for curves and parameters. For this reason, 1000 bootstrap iteration was used for each species investigated. The analysis was carried out using the software SELNET which implements the models described above (Sistiaga et al., 2010; Herrmann et al., 2013).

3. RESULTS

A total of 17 experimental hauls with and without grid panels were conducted during the shrimp beam trawl survey in five different areas of the Sea of Marmara. Besides the target catch, rose shrimp, 61 species belonging to 9 taxonomic groups were determined by the non-sorting grid beam trawl gear. Bony fishes (Osteichthyes) were represented by 21 species, cartilogenus fishes (Chondrichthyes); 2 species, Crusteceans (Crustecea); 8 species, mollusks (Mollusca); 12 species, cephalopods (Cephalopoda); 3 species, echinoderms (Echinodermata); 8 species, anthozoons (Anthozoa); 5 species, *Ascides* sp.; 1 species and porifera (Spongiidae) by 1 species. The catch composition of the sorting grid beam trawl was composed by 34 species of benthic and bentho-pelagic macrofauna belonging to 9 taxonomic groups. These groups and number of species in each group are as follows; bony fishes (Osteichthyes) 15 species, cartilogenus fishes (Chondrichthyes) 1 species, Crusteceans (Crustecea) 3 species, molluscs (Mollusca) 4 species, cephalopods (Cephalopoda) 2 species, echinoderms

(Echinodermata) 5 species, anthozoons (Anthozoa) 2 species, Ascides sp. 1 species and pofires (Spongiidae) 1 species.

CPUE of the non-sorting grid beam trawl in terms of number and weight were 643 ind./h/net and 4.5 kg/h/net, these values were estimated to be 473 ind./h/net and 3.3 kg/h/net for sorting grid beam trawl, respectively. The difference, as mentioned above, was due to escaped or excluded individuals. Despite this lost amount, length distribution-based evaluation showed that 9-11 cm length groups were dominant in the evacuated portion excluded by the window among 6.5-15 cm length groups that entered the net. Although the selectivity was determined for by-catch species passing from the grid and reaching the cod-end, considerable evacuation of small-size by-catch individuals was also observed from the cod-end of the beam trawl.

The existence of many species was observed in the collective bag of the grid beam trawl which was not able to pass through the bar spacing and was directed by the escape window. The reduction ratio of the excluded species in comparison to non-grid gear in terms of number and weight were calculated to be 56,7% and 62,9% for bony fishes, 21.2% and 21.6% for cartilaginous fishes, 30.4 % and 26.1% for crustaceans, 24.5% and 35% for molluscs, 26.9% and 19.9% for cephalopods, 12.2% and 18% for echinoderms, 32.3% and 58.3% for anthozoons, 26,6% and 19.9% for ascides species and both 100% for sponges, respectively. In general, the by-catch reduction of grid-mounted beam trawl gear was determined to be 56.9%. Moreover, the reduction in the target catch (*P. longirostris*) with the mentioned gear was 23.1% and 23.2 in terms of number and weight respectively (Figure 5).

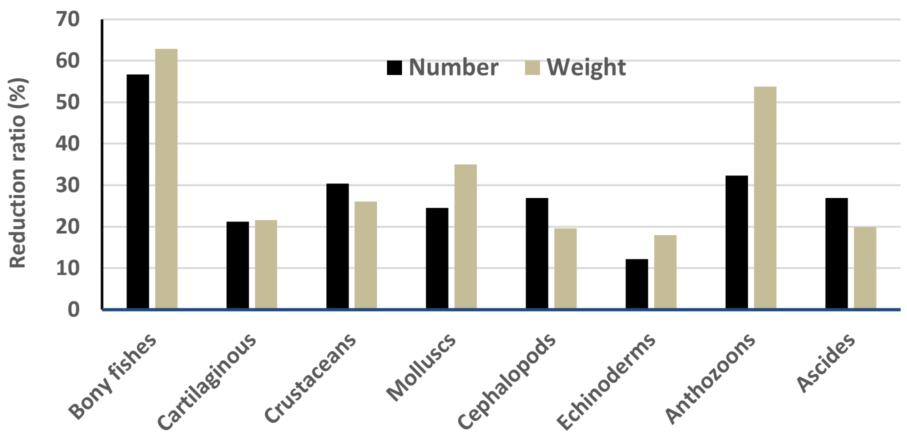

Figure 5. By number and weight reduction rates of non-target species compared to non-grid fishing gear

While the target catch was calculated to be 64.99% and 73.99% for non-grid and grid beam trawl in terms of weight, respectively, the numerical target capture rates were found to be 67.85% and 77.00% for the non-grid and grid beam trawl. This case indicated that rose shrimp is the target species for both gears. Flatfish (turbot, common sole, skates, and rays), categorized in by-catch fraction, were generally excluded by the escape window due to obstruction of the grid. Similarly, fusiform bony fishes (hake, whiting, shore rocking, horse mackerel) were also excluded at a higher rate in number and weight compared to other taxonomic groups.

It was found that 15% of the shrimps escaped via an upper window and 8 % were captured at the cod-end. Moreover, 34% of the individuals placed at the cod-end, were captured in the cover. Small-sized individuals of other species composing the by-catch, especially the juveniles, accumulated in the cod-end together with shrimp. Whereas the length groups of shrimps that escaped to the cover was between 8.5 and 10.0 cm, they ranged from 8 to 12.5 cm in the cod-end. Furthermore, 14.5-15.5 cm length groups were determined among the individuals which couldn't pass through the grid and escaped (Figure 5).

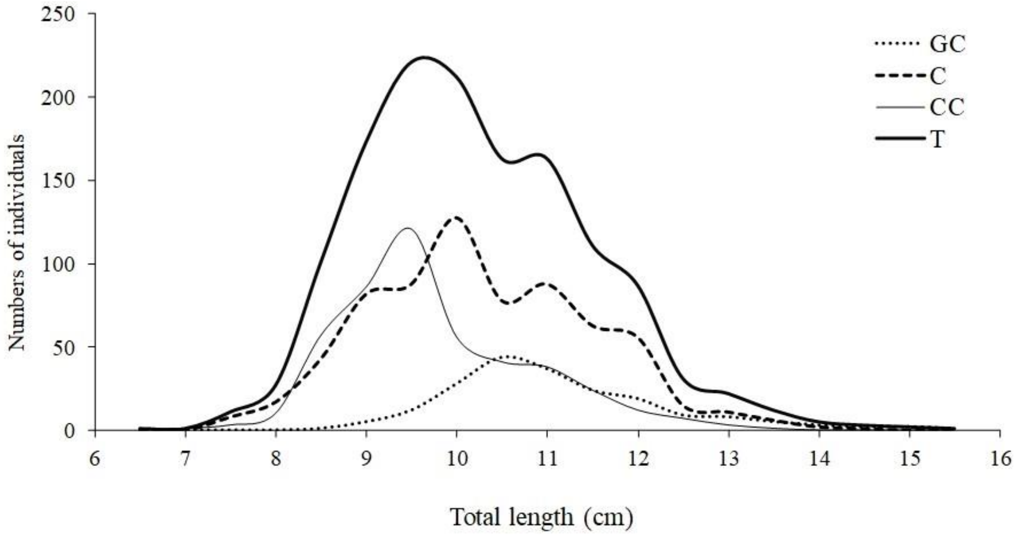

Figure 6. Size distribution of rose shrimp caught in sorting grid (GC: Grid Cover; C: Codend; CC: Cover Codend; T: Total numbers of individuals).

The retention ratio of by-catch species was determined according to a place of capture as in front of grid (collective bag of the escape window) and behind the grid (cod-end). While 50.8% of European hake, 69.1% of whiting, 39.2% of tube gurnard, and 59.4% of common sole were captured in front of the grid, the rest was caught at the cod-end. Length distributions of excluded and captured (in the cod-end) individuals were determined as follows respectively; European hake 11-42 cm and 5-24 cm, whiting 10-27 cm and 8-18 cm, tube gurnard 8-26 cm and 6-19 cm, common sole 7-25 cm and 5-19 cm.

Bigger individuals of fusiform species such as European hake and whiting were observed to escape via the panel of the window but smaller ones passing through the bar spacing gathered in the cod-end. A similar case was also determined for tube gurnard specimens. However, since the tube gurnard entering the net was mostly composed of small individuals that can pass through the grid gaps, a greater proportion of tube gurnard individuals were found in the cod-end. A high exclusion ratio was observed for flatfishes.

According to the results of the selectivity analysis for rose shrimp, many models were applied on SELNET and among those, the one with the smallest AIC value was preferred. The calculated minimum AIC value (1015.21) belonged to RGompertz model for grid selectivity. Selectivity parameters for shrimp in this model were determined to be L_{50} =13.51 cm and SR = 4.76 cm. Rprobit model had the minimum AIC value (1492.88) for 24 mm cod-end selectivity of the same species and the selectivity parameters were found to be L_{50}= 8.99 cm and SR = 5.56 cm. Selectivity curves and confidence intervals of shrimp for grid and cod-end are given in Figure 6. The sigmoid curve in this graph defined the escape of small individuals before a certain length and retain of others in the cod-end after a certain length. Bell shaped curve occurred for the grid selectivity which meant in the transfer of smaller individuals from grid to cod-end and remain of bigger individuals in front of the grid or escape via upper window.

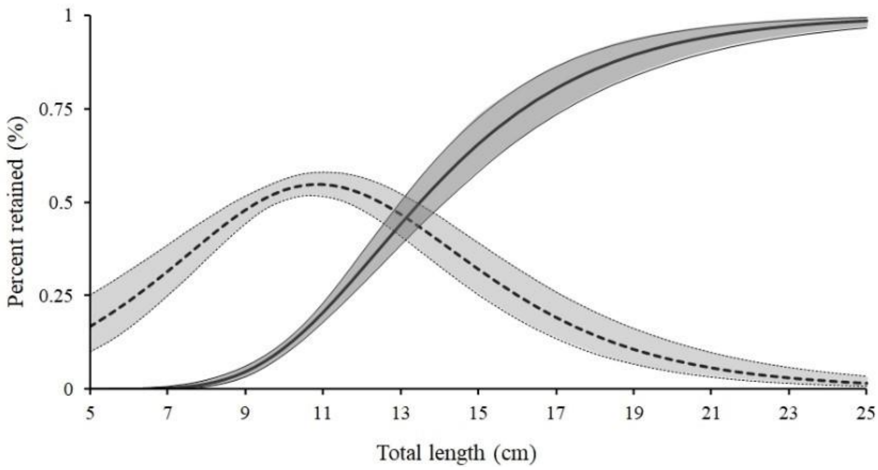

Figure 7. Sorting grid and cod-end selectivity curves with Efron percentile bootstrap 95% confidence limits for rose shrimp (dashed line for sorting grid, straight line for beam trawl cod-end).

Eight models were tested during the grid selectivity analyses for European hake, whiting, tube gurnard, and common sole. The most suitable model was determined to be the Probit model for the above-mentioned species except for common sole (Table 1). Parameters of grid selectivity for by-catch species were calculated as L_{50}=17.88 cm and SR=6.89 cm for European hake, L_{50}=14.44 cm and SR=6.97 cm for tube gurnard, L_{50}=11.89 cm and SR=3.29 cm for whiting and L_{50}=12.82 cm and SR=7.56 cm for common sole.

Table 1. Model selectivity parameter values in SELNET (The lowest AIC value indicates the best fit) for bycatch species.

	EUROPEAN HAKE						WHITING					
Model	*L_{501}*	*SR*	*AIC*	*p-value*	*D.*	*df*	*L_{501}*	*SR*	*AIC*	*p-value*	*D.*	*df*
Logit	17.88	6.55	126.13	1.0000	10.12	35	12.20	3.55	101.24	0.9809	7.19	17
Probit	**17.88**	**6.89**	**124.34**	**1.0000**	**8.33**	**35**	12.26	3.80	101.49	0.9772	7.43	17
Gompertz	17.05	7.26	124.82	1.0000	8.81	35	**11.89**	**3.29**	**99.38**	**0.9967**	**5.33**	**17**
Richard	17.15	7.14	126.86	1.0000	8.85	34	11.93	3.30	101.57	0.9925	5.52	16
CLogit	17.88	6.55	128.13	1.0000	10.12	34	12.20	3.55	103.24	0.9694	7.19	16
CProbit	17.88	6.89	126.34	1.0000	8.33	34	12.26	3.80	103.49	0.9639	7.43	16
CGompertz	17.05	7.26	126.82	1.0000	8.81	34	11.89	3.29	101.38	0.9939	5.33	16
CRichard	17.15	7.14	128.86	1.0000	8.85	33	11.93	3.30	103.57	0.9867	5.52	15
	TUB GURNARD						COMMON SOLEA					
Model	*L_{501}*	*SR*	*AIC*	*p-value*	*D.*	*df*	*L_{501}*	*SR*	*AIC*	*p-value*	*D.*	*df*
Logit	14.47	6.86	99.81	0.5074	18.23	19	12.80	7.42	96.97	0.9478	10.20	19
Probit	**14.44**	**6.97**	**99.20**	**0.5479**	**17.62**	**19**	**12.82**	**7.56**	**96.31**	**0.9635**	**9.54**	**19**
Gompertz	13.90	7.47	99.34	0.5386	17.76	19	12.15	7.34	98.02	0.9151	11.25	19
Richard	13.96	7.36	101.39	0.4681	17.81	18	14.22	9.41	96.56	0.9816	7.79	18
CLogit	14.47	6.86	101.81	0.4409	18.23	18	14.65	5.71	98.67	0.9350	9.90	18
CProbit	14.44	6.97	101.20	0.4809	17.62	18	14.47	6.05	98.10	0.9517	9.33	18
CGompertz	13.90	7.47	101.34	0.4717	17.76	18	14.29	5.64	99.63	0.9001	10.86	18
CRichard	13.96	7.36	103.39	0.4008	17.81	17	14.22	9.41	98.56	0.9708	7.79	17

Even though the length groups of European hake passing from the net mouth to the panel ranged between 5 and 42 cm, lengths of individuals escaping from the panel varied from 17.5-42.5 cm. The smaller individuals which were able to pass through the grid system ranging from 5 to 12.5 cm belonging to the 0 age group gathered at the cod-end. A similar situation also occurred for whiting, tube gurnard, and common sole populations. Although the whiting entering the net varied between 8 and 27 cm, it was determined that mostly 8-12 cm length and 0-1 age groups smaller individuals of the population were in the cod-end. Tube gurnards and common soles entering the net ranged from 6-27 cm and 8-25 cm, respectively, length groups which were not able to exclude via the panel system were composed of smaller individuals of the populations varying between 6-16 cm for tube gurnard and 8-14 cm for common sole (Figure 7).

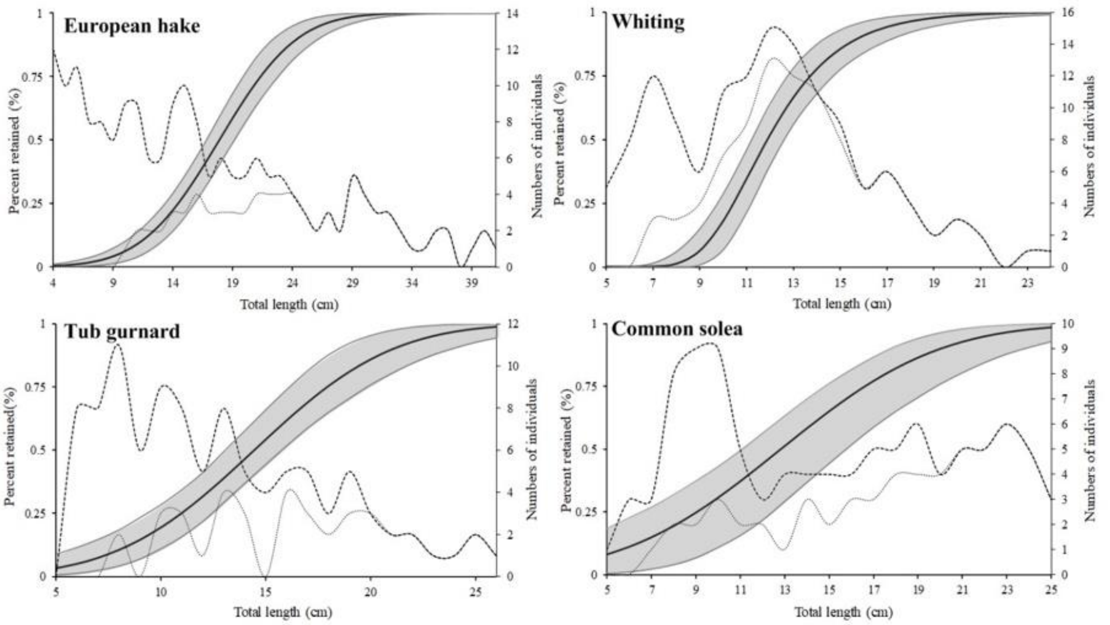

Figure 8. Sorting grid and cod-end selectivity curves with Efron percentile bootstrap 95% confidence limits for others (dashed line for sorting grid, straight line for beam trawl cod-end).

4. DISCUSSION

Findings of the present study especially the behaviors of commercial demersal species (European hake, whiting, tube gurnard, and common sole) sharing the same habitat with rose shrimp in the modified beam trawl net resulted in confirming the targeted approach. Length distribution analysis of these species showed that bigger individuals of the population escaped via the window of the panel according to the bar of the grid spacing and the smaller ones which were able to pass between the grid bars mostly accumulated in the cod-end. Isaksen et al. (1992) reported similar results in *Pandalus borealis* fishery on the exclusion of bigger individuals by the grid. Considerable by-catch problems have been occurring in the Sea of Marmara during commercial fishing operations by bottom trawling gears. A total of 34 species belonging to 9 taxonomic groups were determined during experimental beam trawl fishery operations targeting by-catch reduction by using a sorting grid. Zengin and Akyol (2009) reported 119 species belonging to 10 taxonomic groups together with rose shrimp by traditional bottom trolling gears such as bottom trawl, boat seine, and beam trawl in the Sea of Marmara focusing on the benthic and benthopelagic catch.

During this research, a considerable amount of by-catch reduction was determined by the grid application to shrimp-targeted beam trawl gear in the Sea of Marmara. Bio-economic losses will be able to reduce by decreasing this catch over the long term and therefore benthic biodiversity of Marmara will be protected.

In this study, the grid panel was mounted at an angle of 45º into the cylindrical cage. The full functioning of the system and optimum results depend on placing the grid panel at an appropriate angle. It was reported that the ideal working angle of all shrimp grids must be between approximately

45º and 50º (Isaksen et al., 1992; Larsen, 1996). Boules and Brothers (1996) mounted the sorting grid at an angle of 48º and they reported a 9% increase in the shrimp catch during their experimental study conducted in Canada. If this angle is smaller than 35º, the amount of shrimp loss due to upwards movement may significantly increase in comparison to the number of shrimps passing through the grid. Shrimp loss is much lower at the beginning of the operation at an angle of 50º or wider angles (Larsen, 1996). To reduce the catch of small shrimp in *Pandalus borealis* trawling in Europe and North America, a separation grid with a spacing of 9 and 11 mm has been installed in the Nordmøre style panel net. As a result, it was determined that more shrimp escaped from the grids with 11 mm spacing than 9 mm (He & Balzano, 2012). A similar result was found in this study as well. A decrease of 23.1% in number and 23.2% in weight was determined from the panel with 20 mm grid spacing compared to the traditional mesh. Undoubtedly, these individuals who escaped from the cod end are young and have not yet reached sexual maturity, and at the same time, they are low-priced bioeconomically.

In experimental fishing trials in the Barents Sea by Larsen et al. (2017) the 19 mm bar spacing of the Nordmore grid of the shrimp of the species *Pandalus borealis*, which is a target species in trawling fisheries, has been determined for the four main bycatch species (redfish Sebastes spp., Haddock *Melanogrammus aeglefinus*, Atlantic Cod *Gadus morhua*, and American Plaice *Hippoglossoides platessoides*). According to the findings, it was determined that 80% to 100% of the bycatch species passed from the grid to the bag part. Similar trends were found for other bycatch species. Overall, very few deep-water shrimp have been found escaping from escape.

The escaping ability of by-catch species through a window of the grid system is also influenced by their habitat behavior. Substrate-dependent some benthic species (crab, squid, starfish, sea urchin) are commonly less excluded than free-swimming semi-demersal species (bony and cartilaginous fish) in the benthic and pelagic zone. The exclusion ratio of sandy swimming crab (*Liocarcinus depurtor*) classified in crustaceans was determined to be 57.6% in terms of number and 44.9% in terms of weight in the present study. These results are largely due to the individual catch sizes of these populations. Flatfish (turbot, common sole, skate) of the by-catch fraction were generally excluded via window due to obstruction of the grid. Graham (2003), in a similar study, revealed the significant impact of excluding 0 and 1-year-old age groups of European plaice (*Pleuronectes plattesa*) which composed an important part of the population, during shrimp catch for the commercial plaice fishery. Less swimming ability of smaller individuals in comparison to bigger ones was also reported to be a reason why small fish in the by-catch couldn’t get out via the escape window (Larsen, 1996).

In experimental studies, the amount of catch per unit effort caught by conventional beam trawls is in number and weight, respectively; 643 ind./h/net and 4.5 kg/h/net; for modified nets, these values were estimated as 473 pcs/hr/w and 3.3 kg/hr/w. As mentioned above, the difference comes from the individuals escaping/expelled from the grid/panel system. Despite this loss amount, when evaluated in terms of height distribution; It was determined that in the total shrimp catch, which entered the net and ranged in length between 6.5-15.5 cm, mostly 9-11 cm size groups were thrown out of the window. Small individuals of non-target species were also observed to be largely expelled from the beam trawl cod end.

Females of the rose shrimp population reach sexual maturity at 9.7 cm (total length with rostrum). The reproduction activity of *P. longirostris* population in the Sea of Marmara starts from the beginning of the first age (Zengin et al., 2004). Selectivity investigations on *P. longirostris* population indicated that the size and shape of meshes at the beam trawl cod-end must have been 28 mm diamond or 24 mm square for an optimum fishery (Zengin and Tosunoğlu, 2006). Cod-end selectivity value of

8.99 cm showed that 24 mm mesh size net used in the study was insufficient. The calculated selectivity value of the grid (L_{50} = 13.51 cm) is significantly higher than the sexual maturity value. But composing very little loss of 15% in the total catch is considered to contribute to the sustainable shrimp fishery.

Considered together with the selectivity findings; In algarna nets with a bag mesh opening of 28 mm/prism and a separating grid/panel, although the amount of shrimp escaping from the window part of the panel was up to 25%, with the selectivity provided in the codend of the net (with the selectivity provided in the codend in shrimp catch). A portion of 44.4%, mostly consisting of juveniles and young individuals, is returned to the ecosystem.) Fishing large-sized individuals will provide a significant advantage in terms of both the shrimp population in the Sea of Marmara and commercial value.

5. CONCLUSION

It is stated that shrimps have poor swimming ability in the targeted direction concerning fish. Shrimps which are passive swimmers in comparison to fish move randomly in the water and enter the trawl cod-end without any escape. These behavioral characteristics represent important design information for fish escapes quickly from the panel net with strong swimming ability. In the first step, grid beam trawl design benefits from swimming performance differences between by-catch fish, and shrimps and fish moving at high speed are effective in escaping from the panel. On the other hand, the average length of fish entering the net is also an important factor to escape. Because the escape of smaller fish from the net panel is lower than the others (Eayrs, 2007). The results of this study confirm these general approaches.

Güngör et al. (2007) reported that the length distribution of the landed shrimps was more effective on the market-value policy than the amount landed in a study focusing on the socio-economical characteristics of fishery in the Sea of Marmara. From the perspective of fishermen's economy, it has been seen that shrimp catch with panel/grid modified beam trawl net was more advantageous. When the benefits of the system are considered as a whole; (1) besides an optimum shrimp fishery (2) Species diversity in the benthic ecosystem in the Sea of Marmara will be protected up to 50-55%.

Some economic advantages of using a horizontal sorting panel in the shrimp fishery on the market price were revealed. First of all, the income of the fishermen may be raised by increasing the quality of the landed shrimp. Preventing over-quota problems, decreasing on-board efforts and capturing only target species, and exclusion of other bycatch species and undersized individuals are the other beneficial cases. The use of horizontal sorting panels was reported to increase the trawl resistance by approximately 10% and this was counted to be negligible for fuel consumption but it was also stated to be non-effective on the height of the net (Wileman, 1994).

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CONFLICT OF INTEREST

Example: 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.

AUTHOR CONTRIBUTIONS

Editing: MZ; Methodology: MZ, HK, ZT, TY, UU; Experiment: MZ, HK, ZT, TY, UU; Data analysis: MZ, HK, ZT, TY, UU. All authors approved the final draft.

ETHICAL STATEMENTS

Local Ethics Committee Approval was not obtained because experimental animals were not used in this study.

DATA AVAILABILITY STATEMENT

The data used in this study are available upon request from the corresponding author.

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