Effect of Ground Gear Modification on Bycatch of Rays in Mediterranean Bottom Trawl Fishery

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Abstract

Bycatch of rays and skates in towed fishing gears represents one of the major threats to these relatively slow-growing marine species. The objective of this study was to modify ground gear in a bottom trawl fishery to increase the escape of these species during towing without associated loss of target catch. Sea trials were carried out with a research vessel in Mersin Bay, North-eastern Mediterranean. Experimental ground gear was modified by cutting the rigging twine between the fishing line and the footrope in the central part of the ground gear. Capture of three unwanted bycatch species were estimated. The probability of capture of guitarfish (*Rhinobatos sp.*) and common stingray (*Dasyatis pastinaca*) was significantly reduced to 8% and20% for guitarfish and stingray, respectively compared to standard ground gear. The results for spiny butterfly ray (*Gymnura altavela*) were inconclusive due to the wide confidence intervals. Further, the catch comparison results for five out of six target species investigated did not show significant reduction in catch efficiency when using experimental gear compared to the standard trawl. Only for common sole (*Solea solea*) the modified trawl had significantly lower catch efficiency than the standard trawl. We believe that this technical measure for reducing unwanted bycatch in bottom trawls has a potential to be adopted by the fishery due to being an efficient, low-cost measure which does not create additional challenges during handling of the gear.

1. Introduction

Demersal trawl fishery in the Mediterranean Sea has a multispecies nature and elasmobranchs compose a significant component of the catches. Özbilgin et al. (2013) reported that nine species of elasmobranchs, which are listed either as threatened or data deficient by the IUCN (Cavanagh and Gibson, 2007) are captured and discarded by trawlers in Mersin Bay. These species have no significant value in Turkish market. Additionally, they have become a focus of interest for marine conservation in recent years (Öztürk, 2018). As of 2018, 22 shark and ray species have been placed under protection in Turkish Fishery Regulations (Anonymous, 2020). Rays and skates are vulnerable to bycatch due to being slow growing species with late attainment of sexual maturity and low fecundity (Ellis et al., 2010). Furthermore, their large size and flattened body form, make them sensitive to overfishing and resulting discard by static and towed gears, especially in mixed demersal fisheries (Kynoch et al., 2015).

From both ecosystem and economic point of view, discarding of unwanted species in fishery has been identified as a significant problem (Fauconnet et al., 2015). The rough average estimate of discard in fisheries across the Mediterranean is around 230 000 tonnes annually which corresponds to 18.6 % of the average annual catches (Tsagarakis et al., 2014). The bottom trawl fishery is responsible for majority of this figure in all geographical subareas. In terms of numbers, sharks and rays are the second largest group of total reported incidental catch of protected species (FAO, 2020). Specifically, in Mersin Bay trawl fishery, discard ratio for 136 species entering the trawl was estimated to reach 48 % of the total catch in terms of weight and 72 % in terms of numbers (Özbilgin et al., 2013).

In the eastern Mediterranean, large proportion of the gear selectivity studies in the last two decades has been focused on improving the size selectivity of trawl codends with a focus towards the commercial species (Metin et al., 2005; Aydin et al., 2008; Tokaç et al., 2010; Eryaşar and Ozbilgin, 2014; Ozbilgin et al., 2014; Deval et al., 2016). Such studies do not provide improvements regarding reduction of elasmobranch bycatch in the fishery. Due to the body shape of those species, the fish cannot escape after reaching the codend, considering that even the small sized individuals are much larger than the mesh size. However, most of the skates are physically impact resistant due to having a skin particularly well protected with thorns and denticles (Ellis et al., 2010). Therefore, if such species could be prevented from entering the trawl, their survival following a ground gear pass over the top of them is potentially higher compared to survival after being discarded following the gear retrieval (Enever et al., 2010; Saygu and Deval, 2014).

Bottom trawl footrope modifications may have a potential to reduce entry of some of the bycatch species into the trawl. Modifications in footrope have been effective in reduction in the interaction of bycatch species with the ground gear (Graham, 2010; Hannah et al., 2011; Bayse et al., 2016) by applying; lightening/removing some components or using lights on ground gear (Hannah et al., 2015; Kynoch et al., 2015; Farriols et al., 2021) or raising the footrope (Hannah and Jones, 2000; Krag et al., 2010; Chosid et al., 2011; McHugh et al., 2017). Therefore such modifications can mitigate the bycatch due to interspecific behavioural and morphological differences of the different species (Melli et al., 2018). Underwater observations in Mersin Bay demonstrated repetitive escape attempts of some elasmobranchs under the fishing line (Kalecik, 2018).

In Mersin Bay bottom trawl fishery targeting red mullet (*Mullus barbatus*), common pandora (*Pagellus erythrinus*), lizardfish (*Saurida lessepsianus*) as well as some invertebrate species such as common cuttlefish (*Sepia officinalis*), common squid (*Loligo vulgaris*) and deep-water rose shrimp (*Parapenaeus longirostris*), giant red shrimp (*Aristaeomorpha foliacea*) and blue and red shrimp (*Aristeus antennatus*) the typical commercial ground gear type is composed of two ropes rigged to each other with a small distance between them with an aim to avoid intake of unwanted bottom debris. We applied modifications to the ground gear by disconnecting the rigging in the central section of the trawl mouth area, to provide a potential escape gap for large elasmobranchs. Therefore, based on the observations of previous studies, the present study aims to compare the catches of non-target elasmobranchs as well as the main target species in the modified ground gear versus commercially used standard ground gear in demersal trawl fishery.

2. Materials and methods

2.1. Sea Trials

The experimental trials were carried out onboard research vessel “Lamas-1” (16m, 240HP) between 17 January – 2 May 2017, at 7-45 m of depths, in Mersin Bay, Northeastern Mediterranean (Fig. 1). During the sea trials, 36 hauls were conducted in two different fishing grounds in order to sample both flatfish (i.e., common sole (*Solea solea*), rays and skates) and round fish species efficiently. Therefore, first nine pairs of tows were conducted in the west part of the bay where a higher abundance of red mullet (*Mullus barbatus*), brushtooth lizardfish (*Saurida lessepsianus*) and common pandora (*Pagellus erythrinus*) were expected. Then second nine pairs of tows were performed in the eastern part of the bay where common sole and green tiger prawn (*Penaeus semisulcatus*) are targeted.

The towing speed was between 2.4 – 2.6 knots and tow duration of each haul was restricted to 60 minutes (Table 1). However, due to the technical issues, in one instance the tow time exceeded 60 min, thereby the catch data was used after standardizing it as kg h^{-1}. The start of the haul was defined as the moment when steal warp releasing stopped, and the end of the haul was defined as the moment when warp hauling started. Fishing operations were conducted by using a traditional commercial trawl net which had 600 meshes around the fishing circle. The 44 mm nominal diamond mesh size codend was hand-woven (slack knotted) which corresponds to what is commercially used in Mersin Bay by the demersal trawl fleet (Eryaşar et al., 2014). The codend was made of multi-monofilament (Ø 0.35 mm * 15) polyethylene (PE) twine material, 410 cm in stretched length, and 300 meshes around the circumference. The codend was equipped with a protective bag that was made of 3 mm diameter polypropylene (PP) twine with a nominal 88 mm diamond mesh and 60 meshes on its circumference.

During the tows, GoPro action cameras were mounted in various sections in the trawl mouth area and oriented directly at the centre of the ground gear. The video recordings were used to determine the underwater performance and effectiveness of both ground gears (i.e., seabed contact, the gap between fishing line and footrope) and to observe escape attempts of rays and skates.

2.2. *Technical specifications of ground gears used in the experiment*

The bottom trawl had one of the most commonly used conventional type of ground gears that are used in the area for reducing marine litter on the seabed. It consisted of two ropes rigged to each other with a 7 cm distance by means of a 3.5 mm diameter PP twine (Fig. 2). The overall ground gear length was 20.8 m. The fishing line was 22 mm in diameter made of polyamide material. The footrope was 28 mm in diameter and was made of combination of lead and nylon. Both standard and modified ground gears were rigged with 60 pieces of lead (1.15 kg/m) and 8 mm in diameter mid-link chain (2.9 kg/m). The experimental ground gear was modified by cutting the rigging twine between the two ropes in the central part (as known as ‘model’) with length of 2.7 m. This corresponded to 13% of the overall length of the ground gear (Fig. 2).

2.3. *Data sampling and experimental method*

We used alternate haul method to collect length measurements (1 cm length classes) and count numbers for the number of individuals for the following six target species; red mullet (*Mullus barbatus*), lizardfish (*Saurida lessepsianus*), common pandora (*Pagellus erythrinus*), common sole (*Solea solea*), green tiger prawn (*Penaeus semisulcatus*) and striped piggy (*Pomadasys stridens*). Further, count numbers of individuals were collected for three bycatch species; guitarfish (*Rhinobatos sp.*), common sting ray (*Dasyatis pastinaca*), spiny butterfly ray (*Gymnura altavela*). In 12 out of 18 alternated haul pairs, subsampling ranged between 0.25 and 0.50 for striped piggy.

The same trawl was used alternately with and without the modification (i.e., standard ground gear vs. modified ground gear). Fishing line and footrope were manually disconnected and connected on the deck on haul-to-haul basis. Thus, any observed differences in the catches between the two gear setups were assumed to be resulting from the horizontal gap we created in the ground gear of the modified trawl.

2.3.1. Unwanted bycatch species

The rates of bycatch for guitarfish, common sting ray, and spiny butterfly ray were estimated for the standard and modified trawl in terms of catch per unit effort (*CPUE*) quantified as a number of individuals caught per trawl haul of each species. The *CPUE's* averaged over all hauls with the specific trawl (i.e., standard or modified) for each of the individual species was estimated by Eq. (1):

$$CPUE = \frac{\sum_{j=1}^{h} n_j}{h} \qquad (1)$$

where n_j is the number of individuals of the species caught in haul j with the specific trawl (standard or modified). h is the number of hauls conducted with the specific trawl. Uncertainties for the *CPUE* estimates was obtained using bootstrapping method by resampling the h hauls catch data and for each resampled data set using Eq. (1) to estimate *the CPUE*. By using 1000 bootstraps, we obtained a population of 1000 estimates for the *CPUE* from which we calculated the Efron 95% percentile confidence intervals (Efron, 1982).

To estimate the relative capture probability of unwanted bycatch species between the modified and standard trawl we needed to account for that catches of those species were scarce, and several hauls did not contain any individuals of those species. Since the hauls were conducted alternately with the standard and modified trawl we paired catch data for consecutive hauls. Specifically, we collected data in pairs for catches in terms of number of individuals for each of the species with the standard (*ns*) and modified trawl (*nm*) respectively. Thus, the number of individuals caught in paired haul j of hauls for the standard (*ns*) and modified trawl (*nm*) for each of the three species separately is denoted ns_j and nm_j respectively. Due to the scarceness in availability of the three observed species, both ns_j and nm_j will be zero for several of the pairs j. However, such pairs contain no information regarding the relative capture probability (*CP*) for rays between the modified and standard trawl and can be ignored in the estimation of *CP*. Accordingly, we let *CCP* represent the expected probability for capture in the modified trawl conditioned capture in one of the trawls. Specifically, we estimate *CCP* by Eq. (2):

$$CCP = \frac{\sum_{j=1}^{q} nm_j}{\sum_{j=1}^{q} \{ns_j + nm_j\}} \qquad (2).$$

where the summation from 1 to q is over only the q pairs of hauls where $ns_j + nm_j \geq 1$. The capture probability *CP* for the modified trawl relative to for the standard can then be obtained from (2) by Eq. (3) (Herrmann et al., 2017):

$$CP = \frac{CCP}{1.0 - CCP} \quad (3).$$

We obtained the estimates for the Efron percentile 95% CI for *CP* by using bootstrapping method with 1000 replications as described above. However, in this case the resampling is conducted over pairs of hauls and including only pairs where $ns_j + nm_j \geq 1$. In bootstrap replication, the value for *CCP* based on Eq. (2) is first obtained and then based on the value for *CP* by applying Eq. (3).

The estimate for *CP* with uncertainties was obtained individually for guitarfish, common sting ray and, spiny butterfly ray by using Eq. (2) and Eq. (3) as described above.

The analysis described in this section was conducted using the statistical tool SELNET (Herrmann et al., 2012).

2.3.2. *Target species*

Using the catch data from the sea trials, we conducted length-dependent catch comparison and catch ratio analyses for paired trawl catch data following the procedure outlined in Lomeli et al. (2020). The purpose of the analysis was to obtain a practical estimate for the relative change in size dependent capture efficiency from the standard trawl to modified trawl for each of the six target species investigated. The analysis was carried out independently for each species following the description below.

To assess the relative length-dependent catch comparison rate (CC_l) of changing from the standard to the modified gear, we used Eq. (4):

$$CC_l = \frac{\sum_{j=1}^{m} m_{lj}}{\sum_{j=1}^{m}\{ns_{lj} + nm_{lj}\}} \quad (4).$$

where ns_{lj} and nm_{lj} are the number n of individuals of the species investigated caught per length class l for the standard (s) and modified (m) trawl, respectively, in haul pair j with the standard and modified trawl. j is the number of paired hauls.

The experimental CC_l in Eq. (4) was modeled by the function $CC(l,\boldsymbol{v})$ using Eq. (5):

$$CC(l, \boldsymbol{v}) = \frac{\exp([f(l, v_0, \ldots, v_k)])}{1 + \exp([f(l, v_0, \ldots, v_k)])} \quad (5).$$

In Eq. (5), f is a polynomial of order k with coefficients $v_0 \ldots v_k$. The values of the parameters $\boldsymbol{v}$ describing $CC(l,\boldsymbol{v})$ are estimated by minimizing the following expression:

$$-\sum_{j=1}^{m} \sum_l \{m_{lj} \times \ln([CC(l, \boldsymbol{v})]) + ns_{lj} \times \ln([1.0 - CC(l, \boldsymbol{v})])\} \quad (6).$$

Minimizing Expression (6) is equivalent to maximizing the likelihood for the observed data based on a maximum likelihood formulation for binominal data. Expression (6) is similar in structure to the SELECT model (Millar, 1993) for data pooled over hauls, which is often applied in the analysis of fishing gear size selectivity (Wileman, 1996). When the catch efficiency of the two trawls is equal, the catch comparison rate becomes 0.5. A catch comparison rate below 0.5 implies that there are significantly fewer individuals of the species of length class l caught in the modified trawl, and vice versa for a catch comparison rate above 0.5.

Based on experience from prior studies (Krag et al., 2015; Santos et al., 2016), we considered f of up to an order of 4 with parameters v_0, v_1, v_2, v_3, and v_4. Considering lower order models as well by leaving out one or more of the parameters $v_0 \dots v_4$, at a time resulted in 31 additional candidate models for the catch comparison function $CC(l,\boldsymbol{v})$. Among these models, the catch comparison rate was estimated using multi-model inference to obtain a combined model (Burnham and Anderson, 2001; Herrmann et al., 2017). Specifically, these models are averaged using Akaike weights as described by Herrmann et al. (2017). The obtained weights are ad-hoc due to between-haul variation is ignored in the estimation based on minimizing Expression (6).

To provide a direct relative value of the catch efficiency between the standard and the modified gear we used catch ratio $CR(l,\boldsymbol{v})$, which relates to $CC(l,\boldsymbol{v})$ by the following equation (Herrmann et al., 2017):

$$CR(l,v) = \frac{CC(l,v)}{[1-CC(l,v)]} \quad (7).$$

If the catch efficiency of both trawls is equal, $CR(l,\boldsymbol{v})$ will be 1.0.

The double bootstrapping method has been used to estimate the 95% CI for $CC(l,\boldsymbol{v})$ and $CR(l,\boldsymbol{v})$. Specifically, the procedure applied here accounts for uncertainty due to between hauls variation by selecting h paired hauls with replacement from the h paired hauls available during each bootstrap repetition. Within each resampled haul, the data for each length class was resampled in an inner bootstrap to account for the uncertainty in the haul due to a finite number of individuals of the species being caught in the paired haul. The resulting data set obtained from each bootstrap repetition was analysed as described above. Therefore, it also accounted for uncertainty in model selection and model averaging because the multimodel inference was included. Based on the bootstrap results, we estimated the Efron percentile 95% CIs for both the catch comparison and catch ratio curve. We performed 1000 bootstrap repetitions. For each species, only hauls with 10 or more individuals were included in the analysis following Krag et al. (2014). The catch comparison and catch ratio analysis were conducted using the analysis tool SELNET (Herrmann et al., 2012).

3. Results

The results obtained in this study were divided into two groups by performing different statistical approach. First, the data for three bycatch species (guitarfish, common sting ray, spiny butterfly ray) was analysed in terms of count numbers of individuals. Second, the data for the six target species (red mullet, lizardfish, common pandora, green tiger prawn, common sole, striped piggy) was analysed including length-based catch information.

A total of 36 valid hauls were included in the statistical analyses. Table 1 shows the number of each species caught in both regions by both gears for each haul. Total catch of the standard gear was 745 kg while the catch in the modified gear was 762 kg.

During the tows, video footages from cameras mounted and oriented directly at the centre of the modified ground gear showed that no failure in terms of gear underwater performance and the size of the gap between fishing line and footrope was detected (Fig. 3).

3.1. Unwanted bycatch species

By modifying the ground gear, two out of three observed elasmobranchs (guitarfish, common sting ray, spiny butterfly ray) were reduced successfully with estimated probability of being captured 8.33% (CI: 0.00-35.20%) and 20.00% (CI: 0.00-73.38%), respectively compared to with the standard ground gear. In the modified ground gear, the CPUE of guitarfish was 0.06 kg (CI: 0.00-0.17 kg), whereas in the standard gear it was 0.67 kg (CI: 0.26-1.21 kg) (Table 2). For the stingray, the estimated CPUE in the modified gear was 0.11 kg (CI: 0.002-0.28 kg) whilst in the standard gear, the CPUE was 0.56 kg (CI: 0.10-1.16 kg) (Table 2). Although the modified gear caught more spiny butterfly ray compared to the standard gear, the results for this species were inconclusive due to the wide confidence intervals (Table 2).

The present study shows that we increase the attempt of these two species to escape through the gap that is created in the modified ground gear (Fig. 4). (Appendix A).

3.2. Target species

The length-dependent catch comparison rate $CC(l, \boldsymbol{v})$ and catch ratio $CR(l, \boldsymbol{v})$ were estimated for six target species (Fig. 5, Fig. 6). The model fits provided *p*-values > 0.05 for common pandora, and green tiger prawn which means a good model representation of the experimental data (Table 3). However, *p*-values were below 0.05 for red mullet, common sole, brushtooth lizardfish and striped piggy (Table 3). Low *p*-values were assumed to be caused by over-dispersion in the experimental data (Wileman et al., 1996) as there were no systematic structure in the deviations between experimental points and modelled curves. Thus, these results were used for applying the model to describe the catch comparison rates also for these four species.

The catch ratio between the standard and the modified ground gears did not show any significant reduction in catch efficiency for the target species except for common sole (Table 3). Therefore both catch ratio and catch comparison graphs have been used only for common sole whereas for the rest of the five target species only catch comparison graph was used.

A significant reduction in catch efficiency was found for common sole for individuals between 17 – 22 cm total length (Table 3) when using the modified gear. The catch comparison curve showed that modified gear reduced the catch both below and above the minimum landing size (20 cm) (Anonymous, 2020) when compared to standard gear (Fig. 5).

The catch comparison curve (Fig. 6) and catch ratio results (Table 3) for common pandora showed that there was no significant difference in catch efficiency between the ground gears on any length classes. Most of the individuals caught by both ground gears were undersized for common pandora.

The modified ground gear effect on red mullet was significant only for individuals 10-11 cm total length which were more effectively caught by modified trawl. The minimum landing size defined by the Turkish Fisheries Regulations (Anonymous, 2020) for red mullet is 13 cm and most individuals were caught above this size (Table 3).

As seen in the Fig. 6, although the catch comparison curve indicated that modified trawl caught more brushtooth lizardfish for some of the length classes (14.5 – 18.5 cm), catch ratio results showed no significant difference in catch efficiency between two ground gears (Table 3).

The striped piggy was the only species caught in all hauls (Table 1). Based on description of catch comparison curve (Fig. 6), the catch ratio did not find any significant impact of modified ground gear on striped piggy (Table 3). Additionally, most of the captured individuals were undersized in both gears.

In the case of green tiger prawn, the catch efficiency did not differ significantly between the two gears (Table 3), although there was an indication of more individuals being captured in the modified gear in all length classes (Fig. 6).

4. Discussion

The objective of this study was to test whether ground gear modifications can reduce elasmobranch bycatch in bottom trawl fishery while maintaining the catch rates of target species. The results of this study reveal that the bycatch of guitarfish and common stingray could be significantly reduced by modifying the ground gear. The commercial bottom trawl was modified by cutting the rigging twine between fishing line and footrope in central part of ground gear. In earlier study, Kynoch et al. (2015) demonstrated that the catch rate of skates and sharks can be significantly lowered by removing the tickler chain which is an optional component of bottom trawls and considered to be especially effective at catching skates and rays. However, this simple technical measure resulted in anglerfish (*Lophius sp.*) catch reduction, which is one of the targeted species in the fishery.

In our study, the length-based catch ratio between the standard and the modified ground gears did not show any significant reduction in target species except for common sole. However, common sole is not the main target species of the trawl fishery in Mersin Bay (Gökçe et al., 2016). The abundance of common sole was relatively low among other target species (151 individuals in 36 hauls; Table 1). Additionally, the size range of the individuals (17-22 cm; Table 3) reduced in the modified ground gear was below or just around minimum landing size. The number of individuals of some species was relatively low for catch comparison in the present study (see Table 1) as it was seen in the CIs around the catch comparison rate and ratio curves (Fig. 5 and 6). However, the fish population structure encountered by the fishing gear during a trawl haul is known to vary from fishery to fishery and even from one haul to another (Herrmann et al., 2016).

The observed reduction of bycatch species (guitarfish and common stingray) in our trials can be explained with differences in species behaviour. As seen in underwater recordings, guitarfish and common sting ray remained close to the seabed (Appendix A), which explains why their escape probability was increased in the modified trawl. In earlier study by Bayse et al. (2016), skates were observed to remain on or near the seabed and most skates (89.7 %) avoided trawl entrance and escaped under the fishing line. Rays and skates, like most other flatfishes, due to their body morphology, are more likely to stay close to the seabed either move forward to their initial heading or change their direction when contacting any trawl component (Bublitz, 1996; Ryer, 2008; Underwood et al., 2015; Bayse et al., 2016; Kalecik, 2018). However, these mentioned studies focused on behavioural observation of flatfish species rather than rays and skates in the mouth of an approaching trawl except for Bayse et al. (2016) and Kalecik (2018). Therefore, the studies of elasmobranch behaviour in relation to fishing gear are limited. In the present study, underwater video recordings (Appendix A) and results of estimated capture probability (Table 2) showed that modified ground gear was effective at avoiding guitarfish and common sting ray capture. However, unlike other two mentioned species, no reduction in catch of spiny butterfly ray was observed (Table 2). One possible reason that could affect capture of spiny butterfly ray may be related to its body-head structure that makes it challenging for this species to turn sidewise. During the video observations, individuals of this species attempted to rise in the water column instead of turning left or right, which resulted in fish, moving above the ground gear and further back in trawl. This manoeuvre was observed also by Bayse et al. (2016) for most flatfish species and has been described by Bublitz (1996). Another reason for this observed reaction may be explained by initial orientation of the fish to the approaching ground gear which can further determine the behavioural choices for some flatfish species (Underwood et al., 2015).

During the 36 hauls, results of underwater observations have not been sufficient to quantify the trawl entrance or escape due to a large amount of turbidity. However, prior underwater observations (Kalecik, 2018) demonstrated that common sting ray and guitarfish species frequently attempt to escape under the ground gears whereas, butterfly ray mostly rises and falls back into the trawl. This tells us prior to gear modification, behaviour observation about these species are of relevance (Graham, 2010).

There are several studies conducted to test the use of grids for mitigating the unwanted bycatch of rays and skates (Brewer et al., 2006; Graham and Fryer, 2006; Grimaldo et al., 2008; Willems et al., 2016). In such gear setup, the species first encounter the trawl, and then swim through the mouth towards the codend and might have a chance to escape through the grid opening. During this selection process, these species might be subsequently injured. This study describes a methodology on reducing the interaction between the fishing gear and the species to prevent those subsequent injuries by exploiting the knowledge of animal behaviour in front of the trawl mouth (Bayse and He, 2017).

To the best of our knowledge, there is only one study focusing on ground gear modification to reduce overall discard in Mediterranean bottom trawl fishery (Farriols et al., 2021). Besides, modification studies exploiting the interspecies behavioural differences, like in our case, are still insufficient in the region. Ground gear modification used in our study provides laterally increased space for dorso-ventrally compressed specimens. However, release of specimens from this increased gap also depends on their preference of entrance height in trawl mouth.

To effectively protect sharks, rays and skates that are included in the Barcelona Convention for the Conservation of the Mediterranean Sea, species-specific management strategies as a solid regional action plan suggested to be implemented by fisheries management organizations (Dulvy et al., 2017; FAO, 2019). Effective technical measures such as raising the footrope (Chosid et al., 2012), removing the tickler chain (Kynoch et al., 2015) or combined bycatch reduction devices (Willems et al., 2016; Melli et al., 2020) are crucial with respect to complementary management measures to reduce the adverse impacts of bottom trawl fishery on vulnerable species and the marine ecosystems. The modification described in this study are based on releasing bycatch species right before the fish have encountered the trawl net. Since such modification is an efficient, low-cost measure which does not create additional challenges during handling of the gear, it can possibly be an encouraging approach to deal with reluctance by fishers to optimize their bycatch reduction performance (Glass et al., 2015; Eayrs and Pol, 2019). However, to ensure effective implementation of such selective gear designs that mitigate the unwanted bycatch species without having significant economic loss, especially in mixed bottom trawl fisheries, it should be considered that catch composition changes between fishing grounds, and seasons. As a future work, this study should be extended to a commercial fishery context by taking into account such behavioural information. If such simple technical measures can prevent rays and skates from being caught and discarded in the fishery, this modification could provide a potential solution for fishers to exclude bycatch of elasmobranchs without losing the target catch.

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Table 1

Overview of the valid hauls showing the region, ground gear types, depth range, effective tow duration, number of each species caught and measured in the standard and modified trawls.

Haul Nr.	Ground gear	Depth range (m)	Towing time (min)	Region	Number of individuals								
							Target				Bycatch		
					MUT	LIB	PAC	SOL	TIP	PKS	GUZ	JDP	RUN
1	Standard	21-27	60	West	118	94	43	0	0	44	1	2	2
2	Modified	21-22	60	West	528	596	132	0	0	24	0	0	0
3	Modified	17-19	60	West	186	106	48	0	0	11	0	0	1
4	Standard	18-19	60	West	408	29	57	1	0	137	1	0	0
5	Modified	14.5-25	60	West	262	70	51	0	0	31	0	0	1
6	Standard	15.5-25	60	West	118	25	30	0	0	17	0	0	1
7	Standard	32-33	76	West	69	93	41	0	1	74	0	0	0
8	Modified	30-31	60	West	79	108	6	0	0	82	0	0	0
9	Modified	43-45	60	West	98	49	87	0	2	111	0	0	0
10	Standard	40-42	60	West	22	41	61	0	0	145	0	1	0
11	Standard	24-30	60	West	130	71	66	0	0	56	1	0	0
12	Modified	24-25	60	West	166	89	34	0	0	52	0	0	0
13	Modified	24-28	60	West	54	41	39	1	0	82	0	0	4
14	Standard	28-28	60	West	72	16	38	0	1	113	0	0	0
15	Standard	36-36	60	West	33	10	32	2	1	9	0	0	0
16	Modified	36-38	60	West	30	15	19	0	0	1	0	0	0
17	Modified	20-24	60	West	498	121	38	0	0	148	0	0	0
18	Standard	23-25	60	West	556	180	70	0	0	82	0	0	1
19	Standard	8-9	60	East	4	0	0	10	33	0	0	0	2
20	Modified	9-9	60	East	3	0	1	3	27	0	1	0	7
21	Modified	7.8-8.5	60	East	1	0	0	3	95	9	0	0	1
22	Standard	7.9-8.4	60	East	0	0	0	9	15	12	1	0	2
23	Standard	7.5-8	60	East	1	0	0	8	63	6	0	0	0
24	Modified	9-9.5	60	East	1	0	0	8	113	21	0	1	4
25	Modified	7.4-7.5	60	East	0	0	4	3	5	97	0	1	0
26	Standard	8.5-8.5	60	East	0	0	8	8	6	110	4	5	0
27	Standard	13.5-16	60	East	0	0	2	0	0	9	0	2	0
28	Modified	13.5-16	60	East	0	0	4	2	0	17	0	0	0
29	Modified	7-7.5	60	East	0	0	0	15	6	62	0	0	0
30	Standard	7.3-8	60	East	0	0	0	29	10	54	1	0	0
31	Standard	13.8-15	60	East	0	0	10	0	0	3	0	0	0
32	Modified	13-14.9	60	East	0	0	7	1	0	9	0	0	0
33	Modified	7.8-7.8	60	East	0	0	0	12	14	64	0	0	0
34	Standard	8-8	60	East	0	0	5	33	16	82	1	0	0
35	Standard	7.5-7.8	60	East	0	0	0	11	10	78	2	0	0
36	Modified	8.2-8.7	60	East	0	0	0	2	11	54	0	0	0
Total number of individuals			**Standard**		**1531**	**559**	**463**	**111**	**156**	**2256**	**12**	**10**	**8**
			Modified		**1906**	**1195**	**470**	**50**	**273**	**2165**	**1**	**2**	**18**

MUT; Red mullet, LIB; Brushtooth lizardfish, PAC: Common pandora, SOL; Common sole, TIP; Green tiger prawn, PKS; Striped piggy, GUZ; Guitarfish, JDP; Stingray, RUN; Butterfly ray

Table 2

CPUE of three bycatch species and their probability of capture in the modified gear. Values in brackets represent 95% confidence limits.

Bycatch species	CPUE Modified Trawl	CPUE Standard Trawl	CP (%) Modified Trawl
Guitarfish	0.06 (0.00-0.17)	0.67 (0.26-1.21)	8.33 (0.00-35.20)
Sting ray	0.11 (0.002-0.28)	0.56 (0.10-1.16)	20.00 (0.00-73.38)
Butterfly ray	1.00 (0.27-2.05)	0.44 (0.12-0.78)	225.00 (6.13-746.13)

Table 3

Catch ratio (CR) results (in %) at different lengths and fit statistics for the catch comparison analysis for six target species. Values in brackets represent 95% confidence limits. * : Out of data range. CR results marked in bold represent significant difference in catch efficiency between modified and standard ground gear.

Length (cm)	CR (%):					
	Common sole	Common pandora	Red mullet	Brushtooth lizardfish	Striped piggy	Green tiger prawn
5	*	100.73 (46.6-2895.33)	*	*	*	*
6	*	101.50 (50.35-2291.44)	*	*	*	613.49 (24.5-169625.08)
7	*	102.02 (48.98-1526.63)	*	*	*	432.81 (25.32-32477.05)
8	91.70 (15.75-2115.65)	102.31 (44.48-926.81)	*	*	97.49 (15.11-1101.35)	309.58 (28.12-6720.98)
9	87.47 (21.71-2090.15)	102.40 (43.71-520.79)	441 (92.9-6021.49)	151.22 (34.4-1027.94)	95.68 (28.83-460.49)	230.3 (33.59-1847.04)
10	82.34 (26.13-1974.51)	102.35 (44.62-311.31)	**314.39 (107.87-1821.86)**	161.2 (60.91-961.3)	94.91 (42.4-263.83)	180.56 (39.85-641.18)
11	76.62 (23.97-1790.86)	102.20 (48.43-214.98)	**226.73 (109.15-780.08)**	171.36 (75.39-861.46)	95.73 (53.38-193.06)	150.08 (45.81-310.44)
12	70.61 (23.08-1522.82)	102.01 (53.05-180.48)	168.65 (95.67-449.39)	181.5 (80.79-772.26)	98.79 (62.06-181.68)	132.7 (56.14-202.41)
13	64.54 (22.07-1138.7)	101.84 (57.89-161.3)	131.67 (78.04-307.71)	191.34 (87.11-690.97)	105.04 (67.43-191.9)	125.19 (62.71-175.43)
14	58.62 (20.54-725.3)	101.75 (49.9-159.86)	109.74 (66.71-240.43)	200.58 (90.21-618.05)	115.91 (69.6-197.73)	126.41 (73.85-176.51)
15	53.03 (19.6-354.47)	101.83 (33.39-231.27)	99.36 (60.8-208.11)	208.87 (92.96-553.26)	133.77 (68.42-240.79)	137.03 (87.02-217.53)
16	47.92 (19.05-179.51)	102.14 (18.47-441.83)	99.47 (58.69-200.53)	215.78 (96.87-488.12)	162.67 (63.9-423.59)	159.94 (95.14-379.66)
17	**43.37 (19.14-92.6)**	102.77 (8.55-1106.77)	112.13 (62.56-221.09)	220.91 (98.62-430.77)	209.46 (51.13-1014.79)	201.5 (93.46-1025.63)
18	**39.43 (20.77-55.66)**	*	144.94 (69.54-315.52)	223.82 (99.81-394.04)	*	273.84 (88.13-4181.1)
19	**36.11 (16.83-43.34)**	*	218.75 (76.42-623.19)	224.11 (97.42-367.48)	*	397.16 (79.95-22250.17)
20	**33.44 (8.09-42.51)**	*	391.16 (76.41-1667.81)	221.43 (93.8-372.45)	*	*
21	**31.47 (3.79-53.69)**	*	835.15 (66.56-6525.81)	215.56 (87.39-406.85)	*	*
22	**30.33 (1.36-85.6)**	*	2124.94 (57.04-45122.45)	206.36 (75.2-484.55)	*	*
23	30.27 (0.51-165.35)	*	*	193.92 (64.14-664.56)	*	*
24	31.70 (0.24-409.27)	*	*	178.51 (49.48-944.34)	*	*
25	*	*	*	160.63 (36.53-1487.1)	*	*
26	*	*	*	141.04 (27.96-2357.44)	*	*
27	*	*	*	120.68 (19.68-3912.98)	*	*
28	*	*	*	100.66 (14.12-6301.93)	*	*
29	*	*	*	82.05 (9.95-10196.83)	*	*
30	*	*	*	65.72 (6.28-14596.57)	*	*
31	*	*	*	52.12 (4.19-25744.49)	*	*
p-value	0.012	0.106	0.004	0.002	0.001	0.126
Deviance	35.44	25.72	41.79	59.46	40.49	29.68
DOF	19	18	21	32	14	22

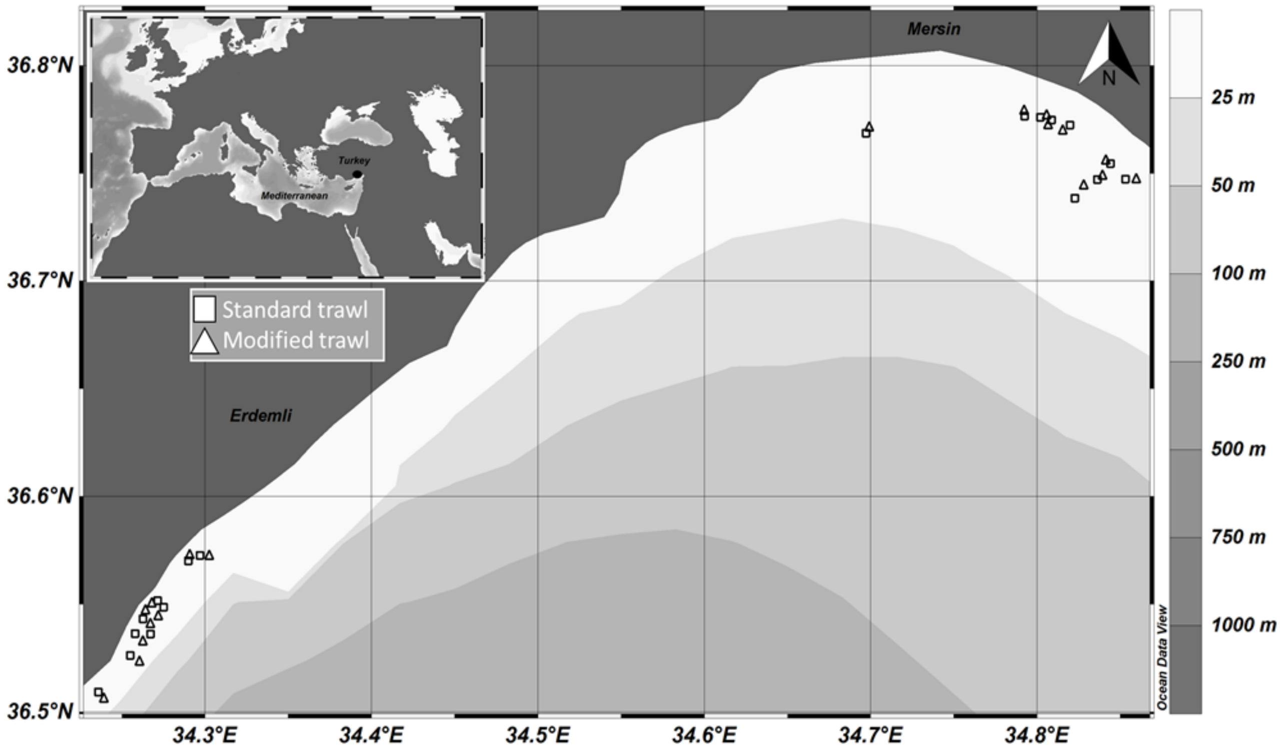

Fig 1. Map of the area off the Mersin coast where tows were started with standard (triangle) and modified (square) trawls. Map source: Ocean Data View, 2022

Fig. 2. Standard ground gear (left), modified ground gear (right)

Fig. 3. Sequence taken from footrope camera showing that the central gap we created between footrope and fishing line before settlement (a) and posture of the modified ground gear on the seabed after settlement (b) in two consecutive frames.

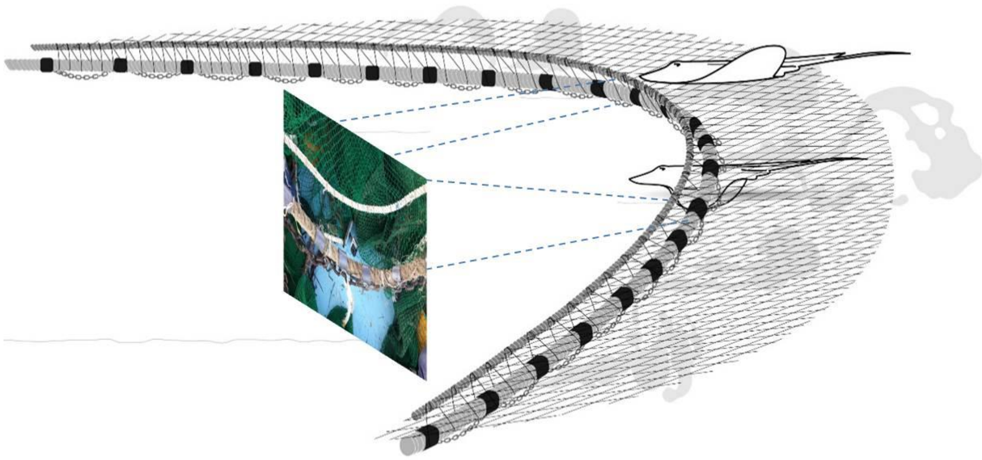

Fig. 4. The gap that was created in the experimental gear (Adapted from Kalecik, 2018)

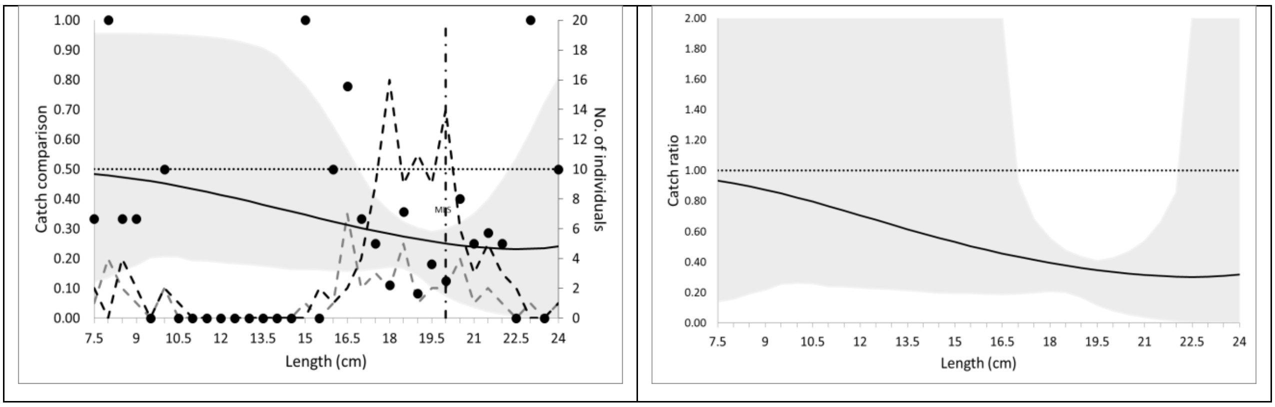

Fig. 5. Catch comparison rate and catch ratio for the Common sole. On the left: the curve (solid line) represents the modelled catch efficiency fitted to the experimental points (dots). The grey band represents 95% confidence intervals and the black (standard) and grey (modified) dashed lines show the length distributions observed in the catch. The dotted horizontal line,

located at 0.50, describes equivalence in catch rates between the two trawls. The vertical dashed-dotted line represents the MLS (Minimum Landing Size). On the right: catch ratio curve (solid line) with 95% confidence intervals (grey band). The dotted horizontal line, located at 1.0 describes equivalence in catch rates between the two trawls.

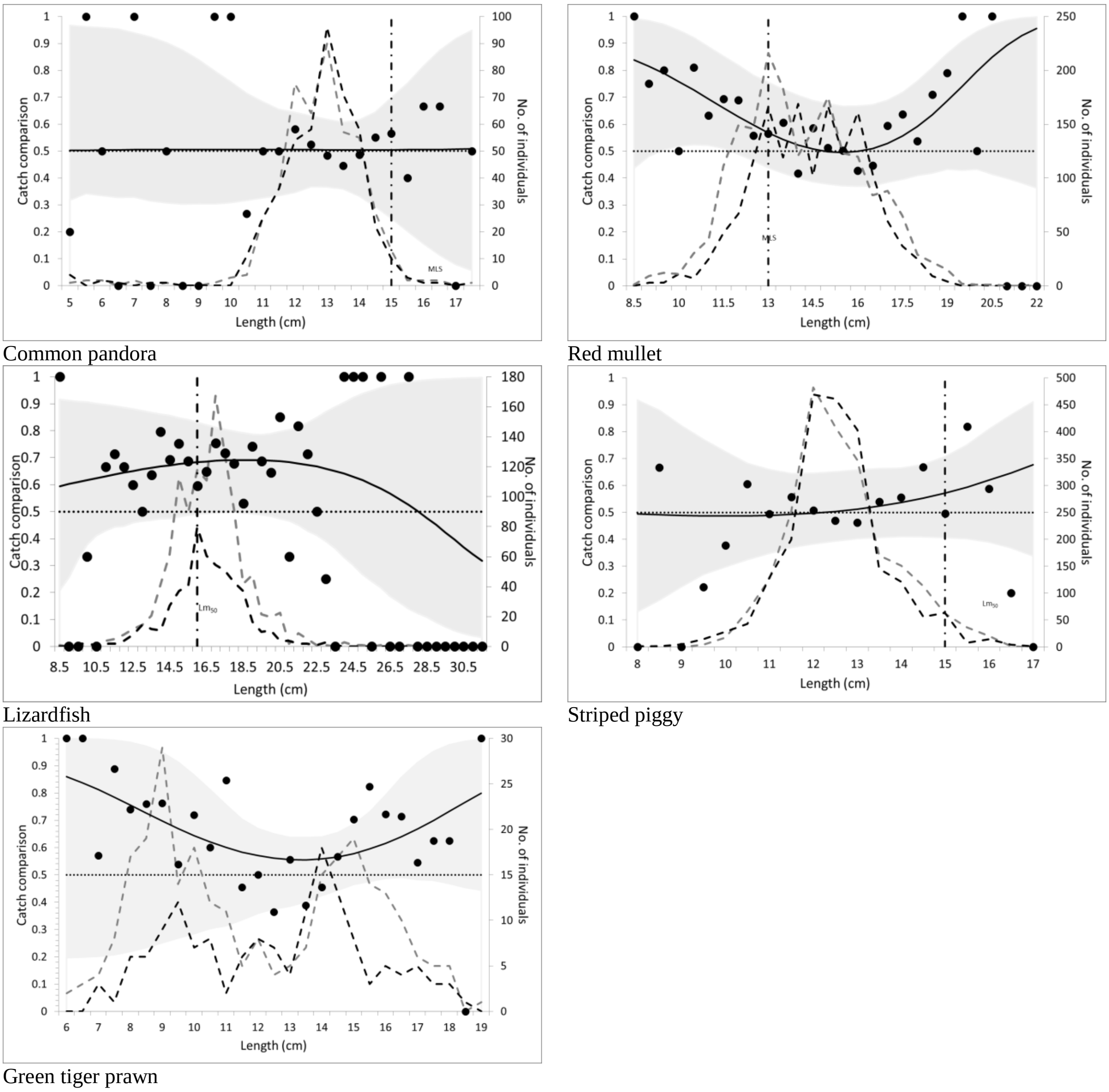

Fig. 6. Catch comparison rates for five target species. On the left: the curve (solid line) represents the modelled catch efficiency fitted to the experimental points (dots). The grey band represents 95% confidence intervals and the black (standard) and grey (modified) dashed lines show the length distributions observed in the catch. The dotted horizontal line, located at 0.50, describes equivalence in catch rates between the two trawls. The vertical dashed-dotted line represents the MLS (Minimum Landing Size).

Appendix A. Video

Video demonstrating stingray, guitarfish and butterfly ray in response to the approaching ground gear. [To view video, click here]