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Original Article

Relationship Between by Catch Ratio of Sardine-Anchovy Targeted Purse Seine and Some Environmental Factors Based on a General Addictive Model in the Aegean Sea

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ABSTRACT

By catch is a serious conservation challenge for the fisheries whose viability is increasingly under threat. To approach maximum by catch reduction with minimum loss of targeted catch, fisheries need to have information on the environmental and anthropogenic factors in multi species seas like the Mediterranean. In this study, we used generalized additive models (GAM) to by the catch ratio of purse seine fishery to determine the effects of environmental variables. The data were collected during each fishing trip in the 2018-2019 fishing season that covers the time period between September 1st and April 15th. There were 26 species (66.216 mt in total) recorded as by catch and the rates of by catch species in the total by catch amount varied between 0.001% and 23.1%. In terms of habitat of by catch species, the total ratios of benthopelagic, demersal and pelagic species were 52% , 28% and 20%, respectively. Significant interactions observed indicate that the fluctuations in by catch ratios differed by depth and sea surface temperature, whereas the quarters of year and the moon phases were not found to affect by catch ratios significantly.

Keywords: Incidental Catch, Mediterranean, Small Pelagic, Depth, Moon Phase Interaction

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INTRODUCTION

The variety of definitions of the term "bycatch" (Alverson, *et al.*, 1994; Casale, 2011; D. C. Dunn, Boustany, & Halpin, 2011; Hall, Alverson, & Metuzals, 2000; Hall & Mainprize, 2005) might be still controversial but it becomes a serious conservation challenge for the fisheries whose viability is increasingly under threat because of overexploited stocks and low economic performance etc. (Maynou, 2020).

The studies on the effect of environmental, spatial variable gear design and sinking performance associated with incidental catch were generally modelled for tuna purse seine fisheries (Escalle et al., 2016; Hu, Harrison, Hinton, Siegrist, & Kiefer, 2018; Martínez-Rincón, Ortega-García, & Vaca-Rodríguez, 2012; Martinez-Rincon, Ortega-Garcia, Vaca-Rodriguez, & Griffiths, 2015; Tang, Xu, Wang, & Zhou, 2015; Tang et al., 2017). However studies on the by catch in small pelagic purse seine fisheries are rather limited (Arcos & Oro, 2002; Marçalo et al., 2015, 2010; Norriss, Fisher, & Denham, 2020; Teixeira et al., 2016; Tsagarakis, Vassilopoulou, Kallianiotis, & Machias, 2012; Tsitsika & Maravelias, 2006, 2008).

To approach maximum by catch reduction with minimum loss of targeted catch, fisheries need to have information on the environmental and anthropogenic factors in multi species seas like the Mediterranean. These studies are also essential to have ecologically based approaches for fisheries management. Because the evaluation of the environmental characteristics of high incidental catch and bycatch is expected to contribute to this management goal. From this point forth, we used generalized additive models (GAM) to by catch ratio during purse-seine operations based on environmental variables to determine the environmental factors that influence the by catch ratio. GAMs have been widely used as a statistical modelling tool to analyse relationships between species distribution and the environment (Martínez-Rincón et al., 2012; Montero, Martinez-Rincon, Heppell, Hall, & Ewal, 2016). Besides, the using of non-parametric smoothing functions, statistical robustness of GAM allows flexible description of complex species responses to environment.

MATERIALS AND METHODS

Data collection

In this study, daily landing data for each operation were obtained from a commercial purse seiner (23.4 m LOA and 313.3 kW). The vessel was equipped with hydro acoustic systems (Two types of sonar - 107 kHz CH-84 model and 160 kHz CH-28, echo-sounder 50- 200 kHz freq.). The purse seine net consists of 5 bulk and 1 bunt, resulting in a length of 750m and a depth of 164m. Though the targeted fish are small and pelagic such as sardines and anchovies, the mesh size of the purse seine net is 13 mm. The data were collected each 174th fishing trip in 2018-2019 fishing season that covers the time period between September 1st and April 15th in Izmir bay by authors via participating in each operation. The major fishing areas were between the depths of 25-68 m. An 8000 watt light source over an auxiliary boat was used to bring together the sardine-anchovy shoals.

Classification of bycatch species

A mean 54% of total European pilchards, *Sardina pilchardus* (Walbaum, 1792), landing and 4.1% of total European anchovies , *Engraulis encrasicolus* (Linnaeus, 1758), landing of Turkey have been found in the Aegean sea for last 30 years (TurkStat, 2021). Therefore, European pilchards (*S. pilchardus*) and European anchovies (*E. encrasicolus*) were accepted as targeted catches for Aegean purse seiners. The species which were retained and sold but were not the targeted species were classified as by catch species. The species which were vulnerable species that were removed from the bunt of the net in the sea (i.e. rays, skates, sun fish), damaged fish, thrown from onboard, and elected small size fish from the grading sieve were named discard. The habitat classification of species were based upon Fishbase (Froese & Pauly, 2019).

The Estimation of by catch ratio

Targeted catch (TC), by catch (BC) and discard (D) were expressed as biomass (kg). The bycatch ratio (BCR) is mainly defined as the ratio of bycatch to total catch, whereby the total catch consists of the targeted catch, bycatch and discard for each haul in a fishing day. The formula is as below:

$$BCR = \frac{\sum BC}{\sum(TC + BC + D)}$$

The estimation of effects of variables on the BCR

The effect of variables on the BCR, was examined by means of Generalized Additive Modelling (GAMs) techniques (Hastie & Tibshirani, 1990). Generalized Additive Models (GAMs) with Tweedie family (Tweedie, 1984; Dunn & Smyth, 2005; Wood *et al.*, 2016) and log link function was used. Although, Tweedie is based partly on the Poisson family, Tweedie distributions are a family of distributions that include gamma, normal, Poisson and their combinations. This distribution is especially useful for modelling positive continuous variables with exact zeros. The Tweedie distribution is parametrized by variance power (p) and the p must be greater than 1 and less than or equal to 2. 1 would be Poisson, 2 is gamma (Tweedie, 1984; Dunn & Smyth, 2005). In this modelling p was chosen 1.01. Restricted maximum likelihood (REML) were also applied as a maximum likelihood-based smoothness selection procedures. The maximum degrees of freedom for each smoothing term, were set to 25 and 14 for Depth and the SST respectively. Therefore, the dimension of the basis used to represent the smooth term (k) were set as 26 and 15 in the GAM formulation. The test of whether the basis dimension for a smooth term was adequate (Wood, 2017) was done by k-index (the estimate of the residual variance based on differencing residuals) and p-value, computed by simulation. The QQ plot of the deviance residuals and the means of randomised quantile residuals were also plotted to check the model (Foster & Bravington, 2013; Pedersen, Miller, Simpson, & Ross, 2019).

Thus, the form of the GAM used was

$$BCR \sim a + s(Dh, k=26) + s(SST, k=15) + Q + MP + e$$

where, a is the intercept, Dh is Depth which is derived from echo sounder , SST is the Sea Surface Temperature (SST data were obtained from the General Directorate of the Meteorological Service (GDMS)), Q is quarter of year as factor variable (i.e. January, February and March are in Q1; April, May and June are in Q2; July, August and September are in Q3; October, November and December are in Q4), MP is the moon phase, which is a factor variable consisting of four periods; new moon, first quarter, full moon and last quarter, and s indicates the smoother function of the corresponding independent variable and e is a random error term.

Statistical inference was based on a 95% confidence level. The model fitting was accomplished using the "mgcv" library (Wood, 2003, 2004, 2017; Wood et al., 2016) under the R language environment (R Core Team, 2020). The "tidyverse" package (Wickham et al., 2019) was also required .

RESULTS AND DISCUSSIONS

There were 26 species (66.216 mt in total) recorded as by catch and the rates of by catch species in total bycatch amount varied between 0.001% and 23.1%. *Boops boops*, *Sardinella aurita*, *Sarda sarda* and *Mugil sp.* were the first four species, therefore the rest of them took a place which is lower than 1% (Figure 1). In terms of habitat of by catch species, the total ratios of benthopelagic, demersal and pelagic species were 52%, 28% and 20%, respectively.

A total of 179 BCRs were calculated during the fishing season. The BCRs were between 0.00125 and 1. The mean BCR is 0.157 ± 0.01. The fact remains that, the median value was recorded as 0.046. In the box plots of BCRs by moon phases, the high overlapping was shown clearly (Figure 2). In terms of quarters of the year, the median values of BCRs have been changing between

0.0204 and 0.0612. Although the median values are relatively the same, the interquartile ranges of Q3 and Q4 were limited according to Q1 and Q2 (Figure 3).

Besides, The QQ plot of the deviance residuals and deviance residuals vs. fitted plot (Figure 4), some diagnostic information about the fitting procedure and results were given in Table 1. As higher p values indicated that the basis dimensions used for smooth terms were adequate and the k-index showed that there were no missed patterns behind in the residuals (Table 1). The deviance residuals against approximate theoretical quantiles of the deviance residual distribution in Figure 4a also showed that the model distributional assumptions were met. Furthermore, the response data were independent, so the residuals appeared approximately as well (Figure 4b).

The analysis of the deviance table indicated that the depths and SSTs were significant (Table 2). Furthermore, the line was undulant in Figure 5. However, a horizontal line was observed in Figure 6.

We analysed data collected from a commercial purse seine vessel in Izmir bay, Aegean Sea to describe the relationship between the bycatch ratio and environmental factors. For the Aegean Sea, *S. pilchardus* and *E. encrasicolus* have been playing key roles as target species but the diverse catch composition of landed bycatch fish confirmed a low species selectivity of this fishery. In contrast to the two species comprising approximately half of the bycatch (~46%), the habitat classification confirmed the heterogeneity of the by catch and the low selectivity of the gear in this study. Tsitsika & Maravelias (2006) stated that 18 species which were 16 fish and 2 cephalopods were recorded as a taxonomic composition of the commercial purse seine catches in Pagasitikos Gulf (Greece) whereas the percentage of demersal fish species landings of the purse seiners had been changing between 1.3% and 8.1% from 1998 to 2007 in the Aegean Sea (Anonymous, 2008). Furthermore, Tsagarakis, Vassilopoulou, Kallianiotis, & Machias (2012) reported that five species (*S. pilchardus, E. encrasicolus, Sardinella aurita, B. boops and S. japonicus*) were considered as the target species for the purse seine fishery in the Aegean Sea, so they represented 97% of the marketable catch. The rest (3%) constituted of fifty five species. For the Black Sea, a total of 26 species including fish (24 species), gastropods (1 species), and crab (1 species) were recorded in the targeted purse seine fishery *E. encrasicolus* and *Trachurus mediterraneus* (Şahin, Ceylan, & Kalaycı, 2015). We think that all these findings could be accepted as normal, because the character of the Mediterranean fishery was described as multi-species catches by Lleonart & Maynou (2003).

In this study, The BCRs were determined between 0.00125 and 1. Şahin et al. (2015) did not calculate the by catch ratio for each operations but they gave the ratio of the by catch in total biomass of the operations targeted, *E. encrasicolus* as 2.1%. In spite of the priority of *E. encrasicolus* and *S. pilchardus* as target species (Anonymous, 2008), the ratio between the discards and the marketable fraction, considering all species, was reported as between <0.01 and 0.15 for the Greek purse seine fishery (Tsagarakis et al., 2012). However this information shows us only the ratios of species not sold to the marketable ones. Hall (1996) stated

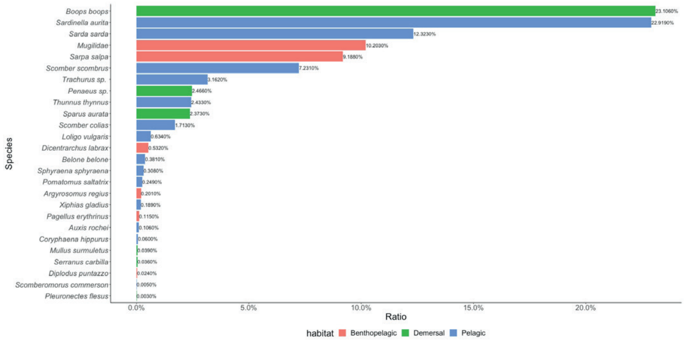

Figure 1. Species ratios in total by catch amount.

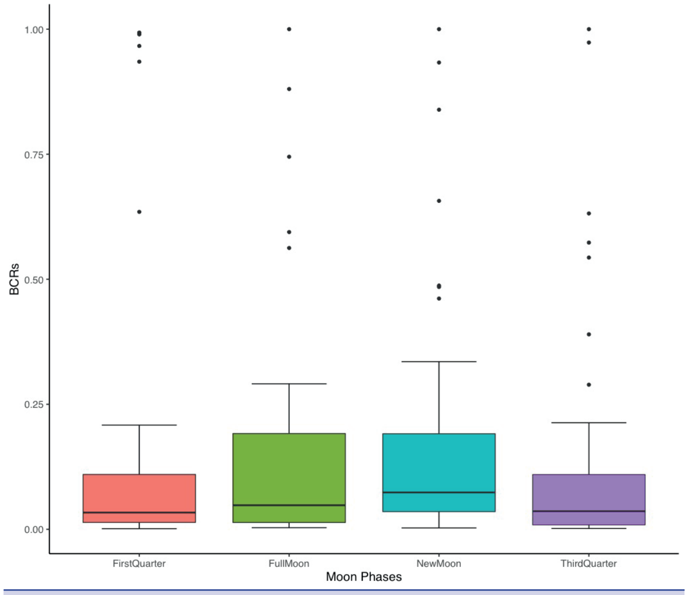

Figure 2. BCRs of purse seine fishery by Moon phase.

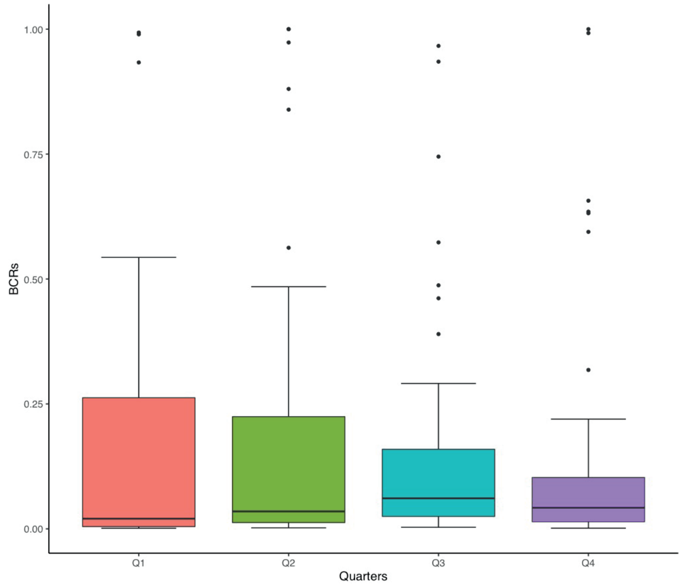

Figure 3. BCRs of purse seine fishery by quartiles of year.

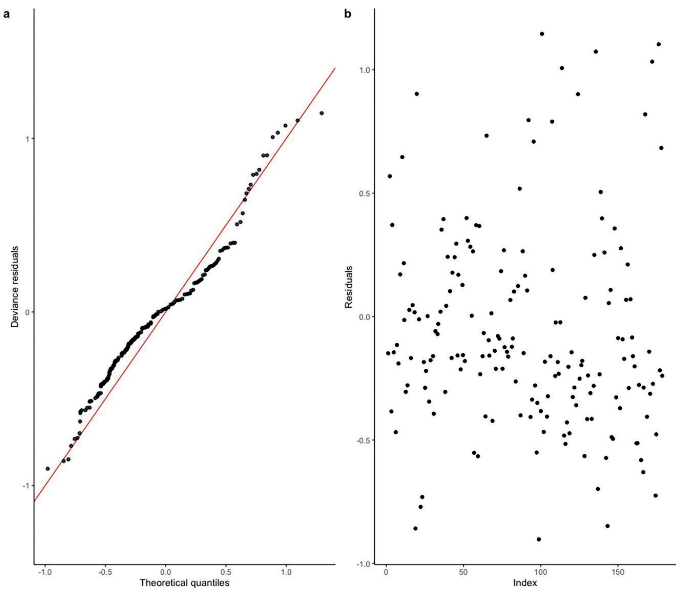

Figure 4. (a) QQ-plot of residuals (black). The red line indicates the 1–1 line. (b) means of randomised quantile residuals.

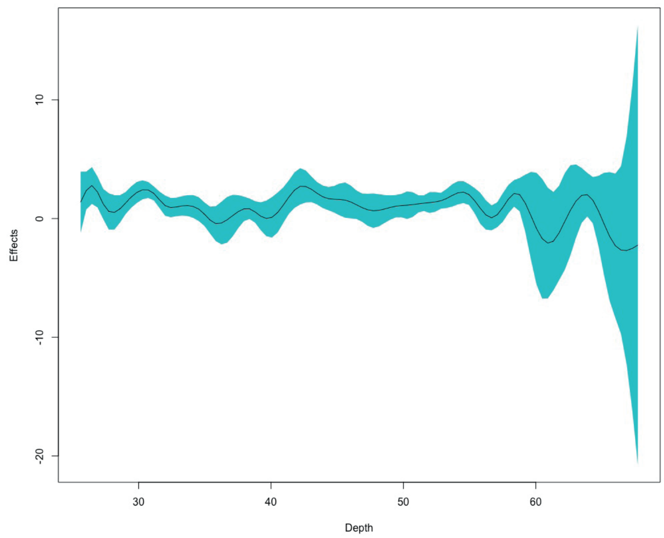

Figure 5. GAM estimated effect of Depth on BCRs for purse seine fishery (turquoise area corresponds to the 95% confidence intervals of the estimates).

Table 1. The result of basis dimensions of model.

Factor	k′,	edf	k-index	p
s(Dh)	25	24.10	1.02	0.74
s(SST)	14	13.50	1.01	0.69

k′= upper limit on the degrees of freedom associated with an s smooth, edf= estimated degrees of freedom. , k-index = ratio of neighbour differencing scale estimate to fitted model scale estimate, p= p value.

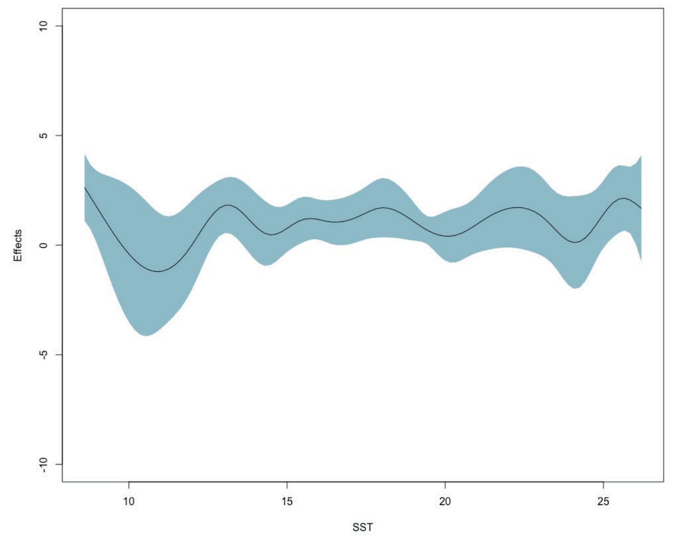

Figure 6. GAM estimated effect of SST on BCRs for purse seine fishery (blue area corresponds to the 95% confidence intervals of the estimates).

Table 2. Analysis of deviance table for the GAM model fitted to the BCR data of the purse seine fishery.

Factor	df	F	p
s(Dh)	24.83	1.748	0.0225*
s(SST)	13.94	1.985	0.0229*
Season	3	0.135	0.939
Moon phase	3	0.910	0.438

*<0.05; df = degrees of freedom, F = F-value, P = P-value, s(x) = smoother function of the corresponding independent variable, Dh= Depth, SST = sea surface temperature.

that the ratios of bycatch to target catch commonly are used as an argument to explain the ecological impact of a fishery. These calculations may help the decision makers and/or scientists to compare between various fishing techniques. Although this ratio is still using in propositions of some Non-Governmental Organizations (NGOs) to ban the tropical tuna purse seine fishery around Fish Aggregating Devices (FADs), by catch ratios might be high when the amounts of target catches were small, with the smallest class of catches responsible for the highest total portion of bycatch while only contributing negligibly to the total target catch (Dagorn et al., 2012). Here, we calculated the ratio or marketable fish (except targeted ones) to the all catch for each operation and we want to point out the margins of the by catch in the targeted fishery that especially are supported with the light located in auxiliary boat to bring together the sardine-anchovy shoals. We think that, these ratios of by catch are normal for each operations in multi species areas such as the Aegean Sea. In the case of the purse seine fishery, which has null mesh selectivity, modern echo-acoustic techniques to search for schools and light using (Colloca et al., 2013), BCRs arise. The inefficient use of resources and changes in the abundance of both target and non-target species make the gear selectivity and an effort reduction beneficial for fisheries resources even on a small geographical scale where co-management can play an important role (Cook, 2010; Guidetti, Bussotti, Pizzolante, & Ciccolella, 2010).

Mannocci *et al*. (2020) developed a generalized additive model for silky sharks (*Carcharhinus falciformis*), oceanic triggerfish (*Canthidermis maculate*), rainbow runners (*Elagatis bipinnulata*), wahoos (*Acanthocybium solandri*), dolphinfish (*Coryphaena hippurus*) and for the Atlantic and Indian oceans relating by catch to a set of environmental covariates (depth, SST etc). Hereby, they stated that the depth and the SST were the most significant environmental covariates as did we. Furthermore, bycatch assemblages around FADs and free school sets from the tropical tuna purse seine fishery in the eastern Atlantic Ocean showed preferences for specific oceanographic characteristics and SST and month also play important roles in describing the diversity patterns of the by catch species (Lezama-Ochoa et al., 2018). Warmer SST contributes to the increased bycatch of sharks per set and high probability of incidental catch of the wahoo, *Acanthocybium solandri* in the tuna purse seine fishery, as well (Martínez-Rincón et al., 2012; Minami, Lennert-Cody, Gao, & Román-Verdesoto, 2007).

Regarding the effect of the moon phase, Jatmiko (2015) stated that the different light intensity in each moon phase may affect the fish in relation to the positive or negative phototaxis properties of light. In fact, Suharyanto *et al*. (2020) stated that the moon phases had no significant effect on the amount of catch, in spite of recording the lowest amount of catch in at the beginning of new moon phases. In contrast to no fishing activity in the lunar phase around a full moon in the Sardine purse seine fishery in Indonesia (Pet et al., 1997), the BCRs were almost the same regardless of the moon phases and there were no effect significant effects in the model of our study. Due to the use of artificial light, the purse seine fishery has been studied in all the lunar phases in the Mediterranean. As commonly known, a purse seine fishery with artificial lights is one of the most advanced and successful methods of increasing the catch rate (Arimoto, Glass, & Zhang, 2010; Dragesund, 1958; Fonteneau, Pallarés, & Pianet, 2000). However, there is a risk of causing an overfishing of the targeted species (Nguyen & Winger, 2019; Solomon & Ahmed, 2016). We think that the effect of artificial light may conceal the effect of moon light on fish species. There may be a need to develop eco-friendly light fishing technologies or fishing regulations to reduce the by catch ratio in purse seine fishery.

Tsitsika & Maravelias (2008) stated that depth was an important factor affecting catches and that most catches were recorded at seabed depths near 30–40m and visual stimuli in the water column is the main factor for the purse seine. Furthermore, Tsitsika & Maravelias (2006) reported that the depth of the purse seine was approximately 30m and most of the fish found within the first 30m of the water column were caught in their study. In fact, the ratios of benthopelagic and demersal species in by catch species were relatively high in our study. We argue that BCRs of the targeted purse seine fishery were affected by depth. Although, the target of purse seine fisheries is pelagic fish, the purse seines can be used to catch high commercial value demersal species such as sea breams (e.g., *Diplodus spp.*, *Pagellus spp.*, *Sparus aurata*) and *Dicentrarchus labrax* (Gonçalves et al., 2008). The high ratios of benthopelagic and demersal species occurred due to shallower fishing areas. However, there were too many peaks in the line presenting the effects of depth in our model. Environmental and geographical factors could play an important role in directing local distribution and variability in the presence of species (Muñoz, Pennino, Conesa, López-Quílez, & Bellido, 2013) but we believe that the high net depth (164m) could be the major reason. The purse seine could be used as demersal purse seine despite its own definition to the contrary.

CONCLUSION

In light of the knowledge of the decline in marine fish stocks and the fishery in the Mediterranean (Colloca et al., 2013; Demirel, Zengin, & Ulman, 2020; Maynou, 2020; Smith & Garcia, 2014; Ulman, Zengin, Demirel, & Pauly, 2020; Vasilakopoulos, Maravelias, & Tserpes, 2014), further studies need to be steered towards the decline in the ratio of the species which were retained and sold but were not the targeted species to the total catch amount in targeted fisheries, and new management arguments like Marine Spatial Planning (Bellido, Paradinas, Vilela, Bas, & Pennino, 2019) should be thrown out for achieving optimal economic-ecological benefits, as well.

Ethics committee approval: The research was approved by the Ege University Animal Experiments Local Ethics Committee in terms of sampling and use of experimental animals with the decision numbered 2018-004.

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