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Spatio-temporal dynamics in the discards of trawl fisheries in the eastern Mediterranean

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Summary: Discarded catches in the main fishing areas of the Turkish coasts of the Aegean Sea were studied using data from commercial trawlers. The study area spans the Turkish coast of the Aegean Sea from Saros Bay (north) to Güllük Bay (south), and data were collected from trawl fishing grounds between April 2010 and 2012. Particular attention is paid to discard per unit effort (DPUE) and discard ratio. Generalized additive modelling (GAM) techniques with Tweedie family and log-link function were used to examine various predictor variables (duration, season, depth, longitude and latitude) on the DPUE of total catch. Discard ratio varied from 0.01 in winter at Çanakkale to 0.90 in summer at Güllük. Total discard ratio was calculated to be 0.33 for pooled data. The DPUE values ranged between 0.2 kg h^{-1} in autumn at Sığacık and 45.5 kg h^{-1} in spring at Güllük, with a mean value of 7.6±5.7 kg h^{-1}. Modelling DPUE values in relation to season vs coordinates revealed spatio-temporal differences. The relationship between the dependent variable (DPUE) and the independent variable (depth) showed fluctuations, but haul duration displayed a decreasing trend in the modelling. It was determined that a considerable amount of trawl discards was obtained in the Aegean Sea. The results of this paper should be considered to create a regional discard policy and management plan in the eastern Mediterranean.

Keywords: trawl; discard per unit effort; Mediterranean; modelling.

Dinámicas espacio-temporales en los descartes de la pesca de arrastre en el Mediterráneo Oriental

Resumen: En este estudio se analizan de forma exhaustiva los datos de descartes de la pesca de arrastre para la flota de pesca comercial turca del mar Egeo. El área de estudio abarca la costa turca del mar Egeo desde la Bahía de Saros (Norte) hasta la Bahía de Güllük (Sur) y los datos se recopilaron de los caladeros de arrastre entre abril de 2010 y 2012. Se prestó especial atención al descarte por unidad de esfuerzo (DPUE) y a la proporción de descarte. Se utilizaron técnicas de Modelos Aditivos Generalizados (GAMs) con la familia Tweedie y la función de enlace logarítmico para examinar varias variables predictoras (duración, estación, profundidad, longitud y latitud) sobre el DPUE de la captura total. La proporción de descarte varió de 0,01 en invierno en Çanakkale a 0,90 en verano en Güllük. La proporción total de descarte fué 0,33 para los datos agrupados. Los valores de DPUE variaron entre 0,2 kg h^{-1} en otoño en Sığacık y 45,5 kg h^{-1} en primavera en Güllük, con un valor medio de 7,6±5,7 kg h^{-1}. El modelado de los valores de DPUE en relación a la estación y coordenadas reveló diferencias espacio-temporales. La relación entre la variable dependiente (DPUE) y la variable independiente (profundidad) mostró fluctuaciones, sin embargo, la duración del lance mostró una tendencia decreciente en el modelo. Se determinó que se obtuvo una cantidad considerable de descartes de arrastre en el mar Egeo. Los resultados de este trabajo deben considerarse para crear una política regional de descarte y un plan de gestión en el Mediterráneo oriental.

Palabras clave: arrastre; descarte por unidad de esfuerzo; Mediterráneo; modelado.

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INTRODUCTION

Fishing is acknowledged to have significant direct and indirect impacts on habitat and biodiversity (Machias et al. 2001). There is a strong emphasis on enhancing environmental sustainability within the fishing industry. This emphasis seeks to strike a balance between ensuring that fisheries remain economically viable and effective at capturing target species at marketable sizes and generating low levels of discards, all while minimizing adverse impacts on the surrounding environment. This approach represents a critical endeavour to harmonize the often-conflicting goals of economic viability and ecological conservation in the fishing sector.

Demersal trawling stands out as one of the most harmful fishing methods, as it tends to result in significant discard and by-catch levels on a global scale. Trawl fisheries operating in the Mediterranean have garnered attention due to their significant discarding practices, though the Mediterranean region accounts for less than 1% of the Earth's total surface water (Damalas et al. 2018). This unique marine environment, rich in biodiversity, accounts for approximately 6% of the world's known fish species (Coll et al. 2010). The Mediterranean fisheries exhibit several unique characteristics when compared with those in other geographic regions, as reported by Stergiou et al. (1997):

1. The Mediterranean region is characterized by highly oligotrophic (nutrient-poor) conditions, which can significantly influence the dynamics of its marine ecosystems.
2. The Mediterranean displays an intermediate variety of species, higher than northern temperate environments and lower than tropical regions, an important aspect of the Mediterranean's ecological profile.
3. Mediterranean waters support a higher number of commercially valuable species than temperate regions, although the diversity of these species is lower than that found in tropical areas.
4. The use of small mesh-sized trawl nets to capture smaller individuals can have a dual impact on the Mediterranean fisheries: it increases the overall diversity of species captured and contributes to a greater number of discards. This highlights the importance of gear selection and its effects on catch composition and discard ratios in the Mediterranean context (Stergiou 1999).

These distinct features make Mediterranean fisheries a unique and challenging ecosystem for fisheries management and conservation efforts.

The discarded portion typically includes non-commercial species, by-catch species and undersized individuals of commercially valuable species. The extent of discarding is influenced by various factors, such as the species composition and the condition of the individuals, as well as the fishing methods, gear, regulatory frameworks and, importantly, market demands (Tsagarakis et al. 2014). Moreover, the estimated discard ratio of 10.8% for the period between 2010 and 2014 amounts to an annual total of 9.1 million metric tons of discards (Roda et al. 2019). Furthermore, in the Mediterranean, an annual discard amount of nearly 240000 metric tons has been reported (Roda et al. 2019).

The landing obligation (Art. 15) for regulated species stands as the primary tool for discard management within the European Union framework, operating under the reformed Common Fisheries Policy of 2013 (Damalas et al. 2018). However, in contrast, discard management measures in Türkiye are currently limited and ineffective, with specific attention not being given to addressing the discarding practices associated with bottom trawl fishery. The total fisheries production in Türkiye was reported as 537000 metric tons in 2012, with 56% of this volume attributed to capture fisheries (Turkstat 2014). By 2022, the total fisheries production had risen to nearly 800000 metric tons, with capture fisheries contributing 328000 metric tons (41%) (Turkstat 2024). The Aegean Sea, a shared fishery resource between Türkiye and Greece, has been subject to substantial bottom trawl fishing pressure for an extended period. Covering approximately one-third of the Turkish coastline, the Aegean accounts for 13.6% of Türkiye's total capture fishery production (Turkstat 2014).

While numerous studies have investigated the selectivity and commercial catches of trawl fishery in Türkiye, less attention has been directed toward understanding discard characteristics specifically along the Turkish coast of the Aegean Sea. In contrast, comprehensive and reliable data are readily available for the Greek side of this region (Maeda et al. 2017, Despoti et al. 2021, Despoti et al. 2024). In the current study, we investigated the impact of various factors, including spatial location, depth, hauling time and season, on the discarded trawl catches in the primary trawling areas along the Turkish coasts of the Aegean Sea, utilizing data collected from commercial fishing vessels. Our approach distinguishes itself from the work of Soykan et al. (2019) by placing particular emphasis on the assessment of discard per unit effort (DPUE) and discard ratios. This study represents the first comprehensive application of generalized additive modelling (GAM) to the dataset, encompassing discarding practices associated with bottom trawl fishery along the entire Turkish coast of the Aegean Sea, from the northern to southern regions. Our study aims to identify key variables, as outlined at the outset of this paragraph, and we anticipate that the findings will serve as a valuable foundation for the development of regional discard policies in alignment with the landing obligations, particularly along the Turkish coast of the Mediterranean.

METHODS

In this study, we used the same data set as Soykan et al (2019) to enhance a novel approach to discarding in the Aegean Sea. Briefly, we provide an overview of the sampling and laboratory analysis procedures, followed by a comprehensive presentation of the data analysis and modelling methods employed in our investigation.

Study area

The study area encompassed the Turkish coast of the Aegean Sea, spanning from Saros Bay in the north to Güllük Bay in the south, corresponding to geographical subarea 22 designated by the FAO General Fishery Commission for the Mediterranean (Fig. 1). Demersal trawling activities are subject to a prohibition in the territorial waters of Türkiye from 15 April to mid-September, as mandated by the Ministry of Agriculture and Rural Affairs. Furthermore, trawlers are allowed to operate in the international waters of the Aegean Sea between mid-July and September. Selected regions are the most preferred fishing zones by the trawlers, and they well represent the Turkish coast of the Aegean Sea from north to south. Bottom trawling in Türkiye has been performed traditionally since the early 2000s, and the structure of the gear with the hauling parameters such as depth and hauling time still remain the same. The mesh size regulation has been assigned to 44 mm in the codend since 2008, and the seasonal and regional closures and target species also remain the same

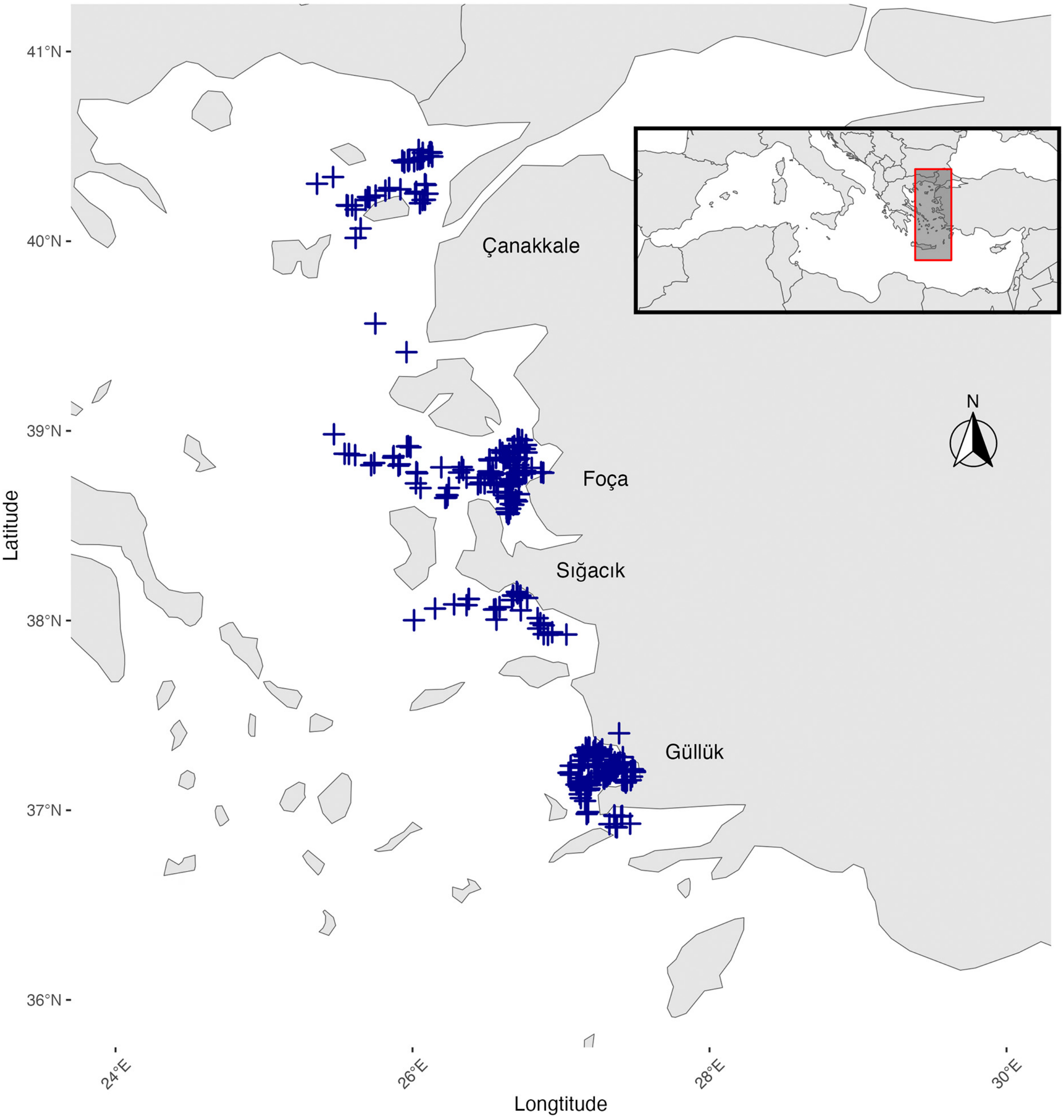

Fig. 1. – Sampling area of the study along the Aegean coast of Türkiye (plus symbol indicates the trawling zones).

(Cerim et al. 2022). In addition, it is important to note that while the number of trawlers within the Turkish fishing fleet was 750 in 2000, the last updated number is 759, indicating a stationary situation (Turkstat 2024). Discarded catch data were systematically collected from legally designated trawling areas (national waters) within the fishing seasons and from international waters during the trawling ban spanning from 2010 to 2012.

Sampling and laboratory analysis

A total of nine commercial trawlers were subject to on-board observations, during which a grand total of 311 trawl hauls were recorded. These vessels, with a length of less than 25 m, were characterized by typical engine power ratings ranging between 400 and 500 horsepower and were equipped with mesh sizes of 44 mm in a diamond configuration. The depth of the trawl hauls encompassed a range of 40 to 450 m, and the average daily trip duration featured an average towing speed of three nautical miles per hour (with a range of 2.5 to 3.5 nautical miles per hour). The duration of individual hauls exhibited variation, spanning from 50 to 430 minutes, with an average duration of 178 minutes accompanied by a standard deviation of 63 minutes (Table 1).

During the study, individuals were categorized as either commercial or discard. A range of data points, including fishing locations (coordinates), depth, start and end times of hauls, haul duration and the percentage of marketable and discarded fractions, were meticulously recorded. The research involved estimating the total catch, documenting the composition of the commercial catch down to the species level, and classifying them as fish, cephalopods or crustaceans. Additionally, a systematic sampling approach was employed to collect data on the discarded portion of the catch. Importantly, the research team refrained from interfering with the standard fishing practices of the crew. Marketable species were retained and stored by the fishers, and their weights were subsequently measured. Further information on the specific sampling strategy employed for discards can be found in the work of Soykan et al. (2019).

Data analysis and modelling

The descriptive statistics of discarding and discard ratios by season and region were calculated. The data concerning the species composition of both landings and discards, categorized by individual hauls, were standardized to hourly yields (kg h^{-1}). To calculate the discard ratio, we followed the methodology outlined by Kelleher (2005) using the formula mentioned below, in conjunction with standard deviation values:

$$d_r = \frac{d}{d+l} \times 100$$

where *d* represents discarded catch and *l* landings.

DPUE and standard error were calculated according to the equation

$$DPUE = \frac{\sum \frac{Di}{nh}}{\sum \frac{t}{nh}}$$

where DPUE represents the discards (kg h^{-1}), Di the discard amount of each operation (kg), t the hauling time (h) and nh the number of hauls. DPUE calculations were based on only the discarded part of the total catch per haul.

To assess the potential collinearity among explanatory variables in our dataset, we conducted a cross-correlation analysis. This involved calculating the correlation matrix, focusing on numeric variables such as location, year, month, depth, duration, latitude and longitude coordinates and DPUE. This approach enabled us to identify any strong correlations between pairs of variables, which could indicate multicollinearity and potentially affect the stability and interpretability of our model results. High collinearity can lead to inflated standard errors and unreliable coefficient estimates, thus compromising the validity of our GAM analysis. Therefore, by evaluating the correlation matrix and visualizing the relationships between variables, we ensured the robustness of our modelling approach and the validity of the conclusions drawn from our analysis. This step aligns with established methodologies in statistical modelling, emphasizing the importance of addressing multicollinearity to ensure the accuracy and reliability of model outcomes (Hair et al. 2010, Montgomery et al. 2015).

We employed with GAM the Tweedie family and a log link function to analyse the influence of season, depth, longitude and latitude on DPUE. Utilizing the Akaike information criterion (AIC), we systematically compared multiple models with varying complexities.

Table 1. – Descriptive information of trawl hauls along the Turkish coast of the Aegean Sea.

	n	Average depth (m)	Average haul duration (min)
Çanakkale	49	273±110	156±67
Foça	77	94±21	163±41
Karaburun	37	230±60	176±48
Sığacık	27	229±60	280±87
Güllük	121	71±15	175±46

The AIC test provides a quantitative measure that balances the goodness of fit with the number of parameters in the model. We selected a variance power (p) value of 1.001 and utilized the restricted maximum likelihood procedure for smoothing. The analysis featured isotropic smooths on the sphere and univariate penalized cubic regression spline smooths (Wahba 1981, Wood 2017). During model selection, degrees of freedom were set as unlimited, and the optimal values were determined by the model itself. The selected degrees of freedom were 10 for depth, 50 for spatial data and 4 for duration, respectively. This methodology is based on works by Hastie and Tibshirani (1990), Tweedie (1984), Dunn and Smyth (2005), and Wood et al. (2016).

The form of the model is

$$\text{DPUE} \sim a + s(D, bs=\text{"cs"}, k=10) + s(lon,lat, bs=\text{"sos"}, k=50) + s(T, bs=\text{"cs"}, k=4) + S + e$$

where a is the intercept, D is depth, lon is longitude, lat is latitude, T is duration of each haul, s is the smoother function of the corresponding independent variable, bs indicates the (penalized) smoothing basis to use, cs represents the cubic regression spline smooths, and sos represents the univariate penalized cubic regression spline smooths. S represents the seasons of year as a factor variable (i.e. December, January and February are in winter; March, April and May are in spring; June, July and August are in summer; September October and November are in autumn), and e is a random error term. The test of whether the basis dimension for a smooth is adequate (Wood 2017) was performed by k-index and *P*-value. A log link function was assumed, and deficiencies of the fitted model were diagnosed by QQ plot of the deviance residuals and means of randomized quantile residual plots (Foster and Branvington 2013, Pedersen et al. 2019). The 95% confidence level was applied.

The “mgcv” (Wood 2003, 2004, 2017), “tidyverse” (Wickham et al. 2019), “gratia” (Simpson 2022), “ggspatial” (Dunnington 2021), “rnaturalearth” (Andy 2017) and “corrplot” (Wei and Simko 2021) packages were also required under the R language environment (R Core Team 2022).

RESULTS

The total catch in this study was determined to be 23560 kg, with 16840 kg allocated for commercial purposes and 6720 kg discarded. The discard ratio exhibited notable variations both seasonally and regionally. Across seasons, the ratio ranged from 0.01 in winter in Çanakkale to a peak of 0.90 in Güllük in summer. When data were aggregated from all seasons, the mean discard ratio was calculated as 0.33±0.20. The examination of discard ratios demonstrated distinctive seasonal patterns, with autumn and winter exhibiting comparable discard ratios of 0.26 and 0.25 (Fig. 2a). Of the regions, Güllük exhibited the highest discard ratio at 0.44, followed by Foça (0.29), Sığacık (0.28), Çanakkale (0.21), and Karaburun (0.21), as illustrated in Figure 2b. A total of 50 species accounted for almost 90% of the discarded fraction in terms of weight (Fig. 3).

A total of 925 hours were spent during trawl operations, and DPUE values ranged between 0.2 kg h^{-1} in autumn at Sığacık and 45.5 kg h^{-1} in spring at Güllük, with a mean value of 7.6±5.7 kg h^{-1} (Fig. 4).

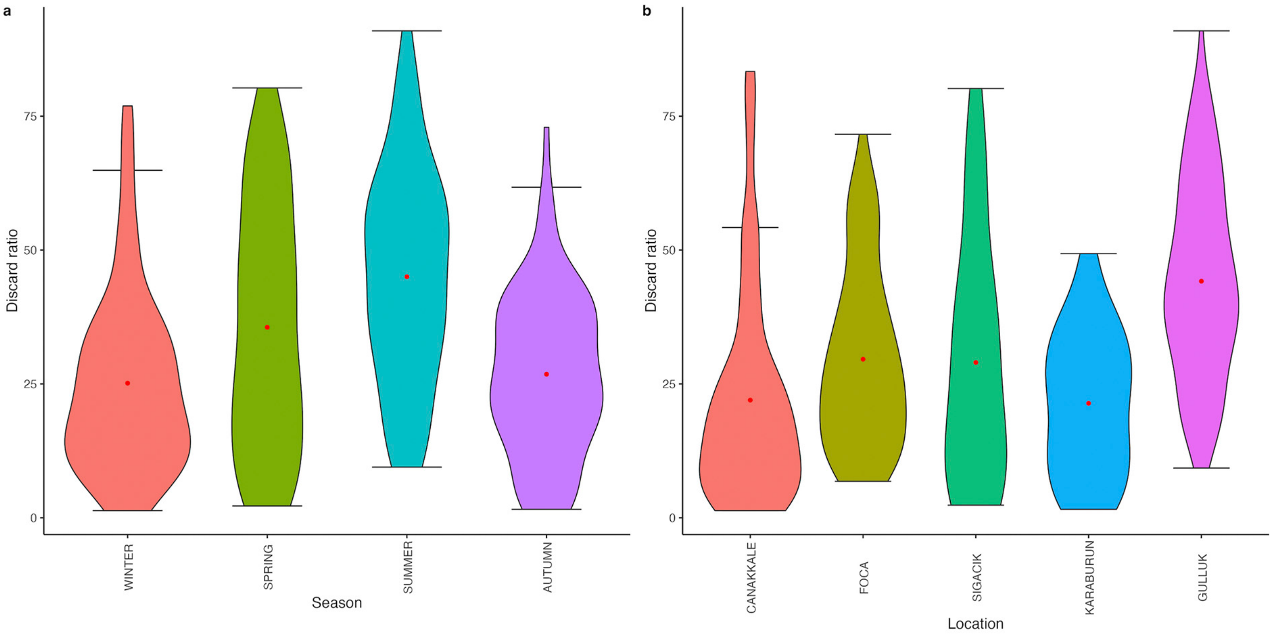

Fig. 2. – Violin plots of discard per unit effort (DPUE) in relation to season (a) and location (b).

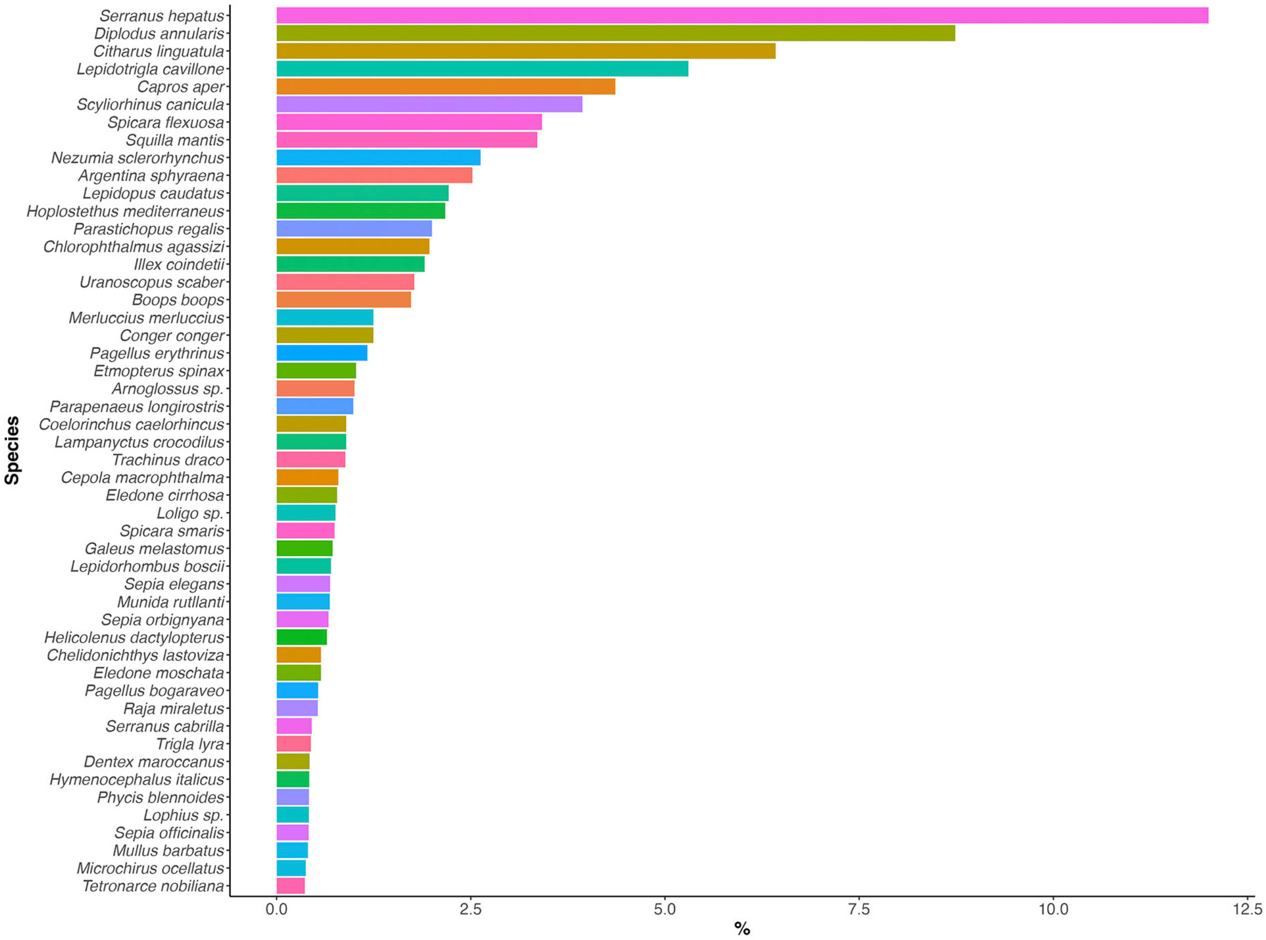

Fig. 3. – Discarded species of Aegean Sea bottom trawl fishery with the greatest percentages.

Although the average DPUE values were similar in autumn (6.3 kg h^{-1}) and winter (6.8 kg h^{-1}), spring showed the highest value (9 kg h^{-1}), followed by summer (8.3 kg h^{-1}). Furthermore, regional comparison showed that Karaburun (8.9 kg h^{-1}) had the greatest DPUE value, followed by Güllük (8.2 kg h^{-1}) and Sığacık (7.2 kg h^{-1}). DPUE values for Çanakkale and Foça were 6.8 and 6.7 kg h^{-1}, respectively (Fig. 4).

Our cross-validation results, as revealed by the correlation matrix, indicated moderate correlations among the variables under scrutiny. However, these correlations did not imply any significant multicollinearity concerns that would impede the incorporation of multiple predictors in our GAM. Notably, the variables Year and Month exhibited a moderate negative correlation ($r=-0.53$), suggesting a discernible seasonal trend over the years (Fig. 5). Additionally, modest correlations were noted between fishing depth and duration time for hauling ($r=0.19$), indicative of a potential positive relationship, yet without signifying multicollinearity issues. Consequently, on the basis of both the cross-validation outcomes and the correlation analysis, it seemed viable to encompass all pertinent variables, including fishing depth and duration time for hauling, within our GAM framework. This comprehensive approach ensured a thorough capture of the varied factors impacting DPUE while sidestepping significant collinearity concerns.

We performed model selection to identify the most suitable representation of our data. Lower AIC scores indicate models that achieve a similar level of precision in predictions with less complexity. Following this criterion, we found that Model 4 exhibited the lowest AIC score among the considered models (Table 2). Consequently, Model 4 was selected as the best-fit model, suggesting that it struck an optimal balance between accuracy and parsimony in capturing the underlying patterns in the data. Some descriptive information about the fitting procedure of the model is also given in Table 3. The distributional assumptions of the model were confirmed to be satisfied, as demonstrated in Figure 6a. Additionally, the plot of means for randomized quantile residuals indicated independence (Fig. 6b). DPUE values differed significantly according to season in the fitted model. Figure 7 portrays fluctuations in the correlation between the estimated GAM effect and depth, with a notable negative wave observed up to a depth of approximately 100 m. Concurrently, Figure 8 reveals a

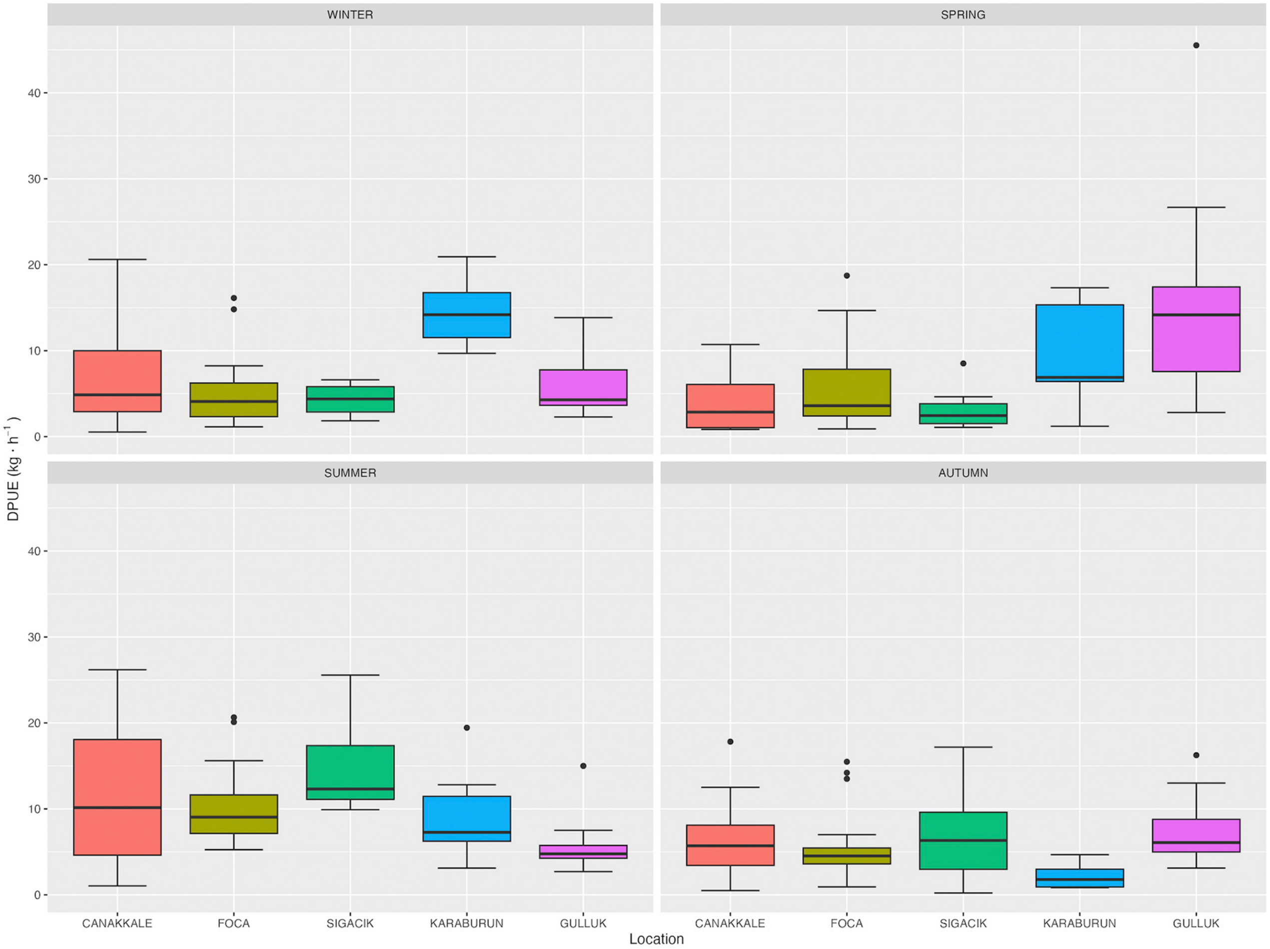

Fig. 4. – Regional DPUE values of Aegean Sea bottom trawl fishery according to seasons.

Table 2. – Model comparison and Akaike information criterion (AIC) values.

No	Model	AIC
1	DPUE ~ a+ s(D, bs=”cs”)+ e	5276.639
2	DPUE ~ a+ s(D, bs=”cs”)+ s(lon,lat, bs=”sos”)+ e	4506.522
3	DPUE ~ a+ s(D, bs=”cs”)+ s(lon,lat, bs=”sos”)+ s(T, bs=”cs”)+ e	4397.138
4	DPUE ~ a+ s(D, bs=”cs”)+ s(lon,lat, bs=”sos”)+ s(T, bs=”cs”)+ S+ e	4204.092

a, intercept; D, depth; lon, longitude; lat, latitude; T, duration of each haul; s, the smoother function of the corresponding independent variable; bs, the penalized smoothing basis; cs, the cubic regression spline smooths; sos, the univariate penalized cubic regression spline smooths. S, seasons of year; e, a random error term.

discernible diminishing trend in haul duration, where an extended duration of hauling is associated with a negative effect, indicating a decline in the estimated effect over time. Furthermore, when compared with the baseline season (winter), the estimated effects for spring, summer and autumn on DPUE were 0.53582 (P<0.05), 0.48959 (P<0.05), and 0.08122 (P>0.05), respectively. These coefficients signify the change in the response variable for each respective season compared with the reference season, with spring and summer showing statistically significant positive effects, while autumn did not exhibit a significant difference from the baseline (Fig. 9). There is a high effect on DPUE in contrast to the blue area, located in most of the Aegean Sea (Fig. 10). It is also noteworthy that DPUE data of the model had statistically significant effects on DPUE in terms of depth, region, haul duration and season (Table 4). Therefore, all variables were major explanatory factors.

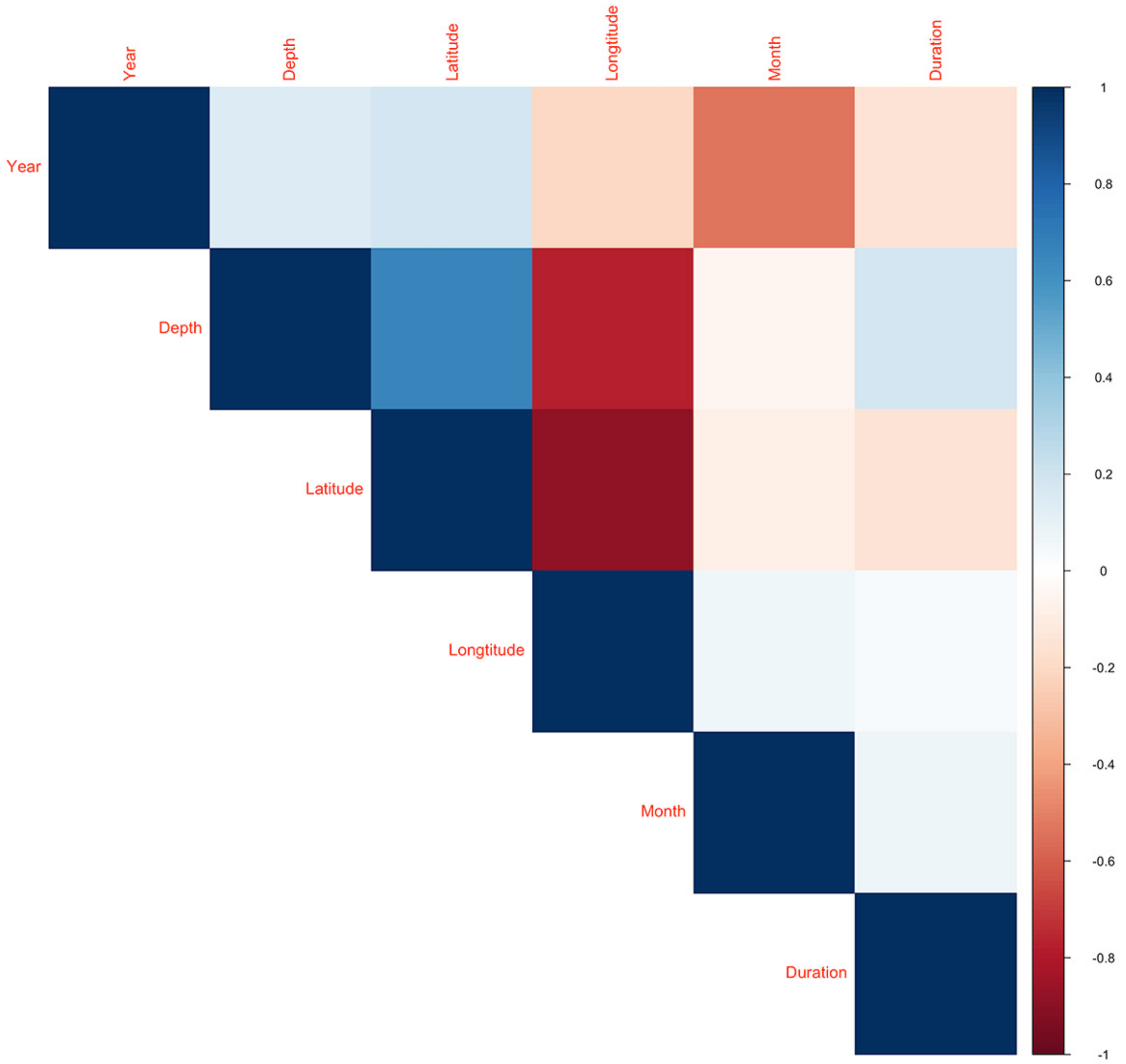

Fig. 5. – Correlation plot illustrating the relationships among variables included in the analysis.

Table 3. – Result of the basis dimensions of the model.

Factor	k’	edf	k-index	P-value
s (Depth)	9.00	7.45	0.92	0.11
s (longitude, latitude)	49.00	43.92	1.07	0.94
s (Duration)	3.00	2.47	0.94	0.24

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.

Table 4. – Analysis of deviance table for the generalized additive model fitted to the DPUE data of the Aegean Sea bottom trawl fishery.

Factor	df	*F*	*P*
s(Depth)	9	3.66	<0.05
s(lon,lat)	49	2.407	<0.05
s(Duration)	3	8.077	<0.05
Season	3	11.95	<0.05

df = degrees of freedom, *F* = *F*-value, *P* = *P*-value, s( ) = smoother function, lon = longitude, lat= latitude.

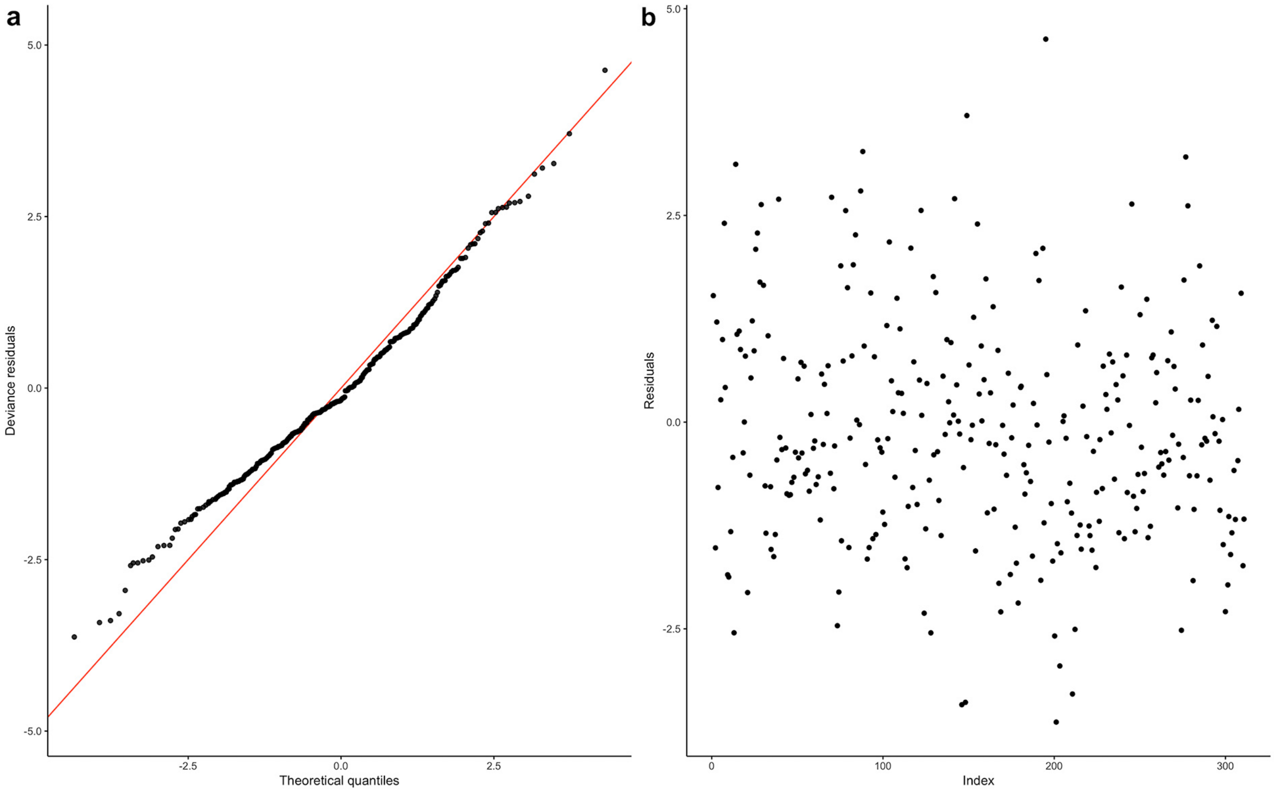

Fig. 6. – QQ plot of residuals (black) (a). The red line indicates the 1–1 line. Means of randomized quantile residuals (b).

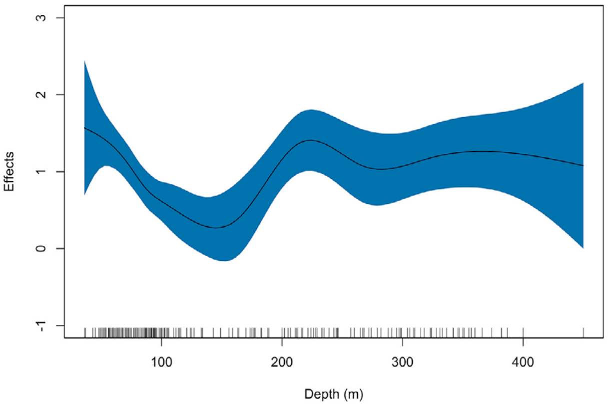

Fig. 7. – Generalized additive model estimated effect of depth on DPUE for bottom trawl fishery in the Aegean Sea (light blue area corresponds to the 95% confidence intervals of the estimates).

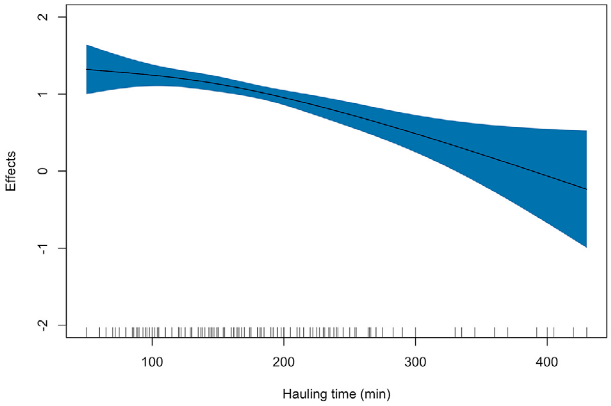

Fig. 8. – Generalized additive model estimated effect of hauling time on DPUE for bottom trawl fishery in the Aegean Sea (light blue area corresponds to the 95% confidence intervals of the estimates).

DISCUSSION

The Mediterranean Sea, known for its high species diversity, presents a significant challenge in terms of discarding practices. Approximately 20% of the annual catches in the Mediterranean region are subject to discard, with 40% of these discarded quantities attributed to the activities of Mediterranean trawl fisheries (Tsagarakis et al. 2014, Damalas et al. 2018). Despite the existence of stringent measures within the European Union aimed at reducing discards in bottom trawl fisheries, the complete elimination of discards remains a formidable challenge because of the inherent heterogeneity in catch composition and the spatial variations across the region.

One of the pivotal studies conducted by Tsagarakis et al. (2024) examined the effect of environmental (longitude, latitude and depth), operational (vessel length overall, vessel age and haul duration), temporal (year, month and quarter) and catch-related (species catch and discard) variables on the discard quantities of certain species representing a wide range in the Mediter-

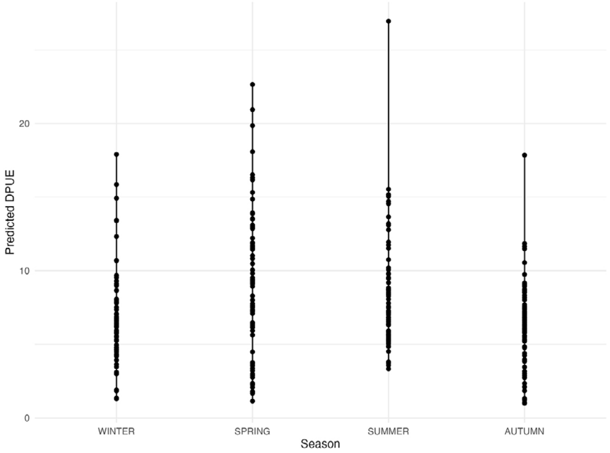

Fig. 9. – Generalized additive model estimated effect of seasons on DPUE for trawling.

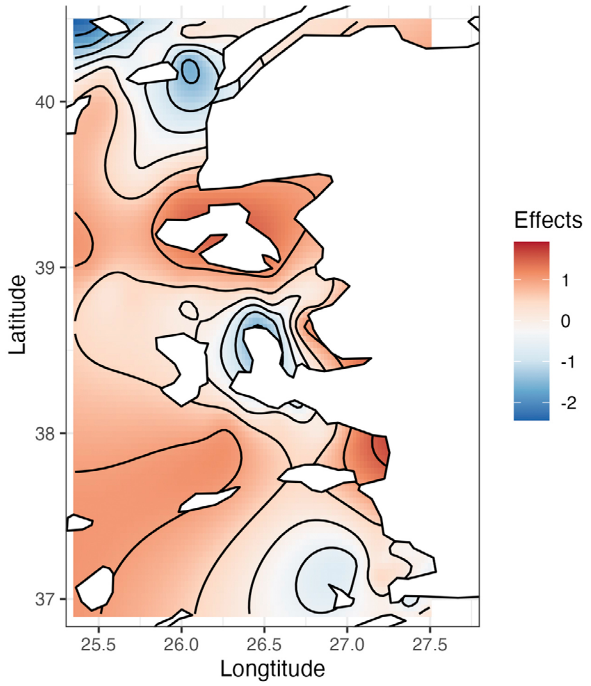

Fig. 10. – Generalized additive model estimated effect of spatial data on DPUE for trawling.

ranean, including a limited part of the Aegean Sea. The authors stated that geographic coordinates and depth were significant covariates but length of the vessel, vessel age and haul duration did not include common patterns across all regions/species in the modelling of discards. Soykan et al. (2019) yielded valuable insights into the spatial and bathymetric distribution of discarded species along the Turkish coast of the Aegean Sea. However, this study did not encompass findings related to fishery parameters, such as DPUE and discard ratios. In the current study, we aimed to bridge this scientific gap by providing comprehensive data on these specific fishery aspects, thereby complementing the findings of the aforementioned study and enhancing our understanding of discarding practices in this region.

In the present study, DPUE values exhibited a wide range, spanning from 0.2 to 45.5 kg h^{-1}, with an average of 7.6 kg h^{-1}. Notably, the lowest and highest average DPUE values were recorded at Foça (6.75 kg h^{-1}) and Karaburun (8.9 kg h^{-1}), respectively. Furthermore, in the seasonal dimension, it became apparent that mean DPUE values varied, with the lowest occurring in autumn (6.3 kg h^{-1}) and the highest in spring (9 kg h^{-1}). This variation in DPUE values highlights the importance of both regional and seasonal factors in understanding discarding practices in this particular area. Depth and season were found to be statistically significant factors in our DPUE-based GAM model. Tiralongo et al. (2021) reported the DPUE values as 10.4 and 13.4 kg h^{-1} for deep (240–500 m) and shallow (50–120 m) waters, respectively, in the trawling zones along the Italian coast. In our study Çanakkale (DPUE = 6.8 kg h^{-1}) can be the representative region for deep zones, while Güllük (DPUE = 8.2 kg h^{-1}) and Foça can be the representative for the shallow zones. Differences between the two studies on DPUE values for deep and shallow waters may be attributable to species diversity of the catch compositions, as Tiralongo et al. (2021) reported 102 and 166 species for deep and shallow waters, respectively, in the central Tyrrhenian Sea, whereas 85 and 134 were found in the present study. Tsagarakis et al. (2014) shared a similar viewpoint, connecting the diversity of catch composition with depth. Although numerous studies have focused on examining the relationship between depth and discarding practices in the Mediterranean (Sartor et al. 2003, Tsagarakis et al. 2014, Damalas et al. 2018, Tiralongo et al. 2021), it becomes evident that the situation is characterized by some controversy, with varying results across these investigations.

Discard ratio is another important parameter indicating the negative effect of a given fishing practice, which is widely pronounced especially in bottom trawl fishery. In the context of the persent study, the discard ratios exhibited a range from 0.22 (Çanakkale) to 0.44 (Güllük), with a mean discard ratio of 0.33±0.20 across a spectrum of 200 species. At this point, our results on discard ratio are in accordance with those of the study of Keskin et al (2014), which was performed near our northern sampling stations (Çanakkale). It is worth noting that several widely cited papers have reported discard ratios in the Mediterranean region, with values falling between 0.26 and 0.44, and the number of affected species ranged from 69 to 309 (Machias et al. 2001, Yemişken et al. 2014, Damalas et al. 2018, Tiralongo et al. 2021). These findings align with the results of our own study, underscoring the consistency of discard ratio patterns across the Mediterranean region. Furthermore, while Edelist et al. (2011) reported a negative correlation between discard ratio and depth, D'Onghia et al. (2003), put forth the contrary viewpoint. Yemişken et al. (2014) reported the discard ratio to be 0.44 for shallow waters (<60 m), constituting 75%

of the total discards in the northeastern Mediterranean trawl fishery. The authors attributed this situation to the higher fish productivity in shallow waters than in deeper waters (>60 m). This interpretation aligns with the findings of Sartor et al. (2003), who similarly observed a higher volume of discards in shallower waters than in deeper regions. These collective observations reinforce the notion that the shallower waters in the Mediterranean exhibit a higher diversity of non-commercial species with undersized individuals of commercial species and, consequently, an elevated proportion of discarded biomass.

Another factor affecting the discard ratio is the introduction of Lessepsian species, as they lead to significant changes in the structure of the coastal fish community within the Mediterranean (Yemişken et al. 2014). Nevertheless, Gökçe et al. (2016) support this observation because they reported that Lessepsian species constituted 45% of the total catch composition in terms of weight in bottom trawl fishery. In the context of the present study, it is important to highlight that discard ratios exhibited variability among different locations. Notably, the highest discard ratio was recorded in the shallowest area, Güllük, while the lowest ratios were observed in Çanakkale and Karaburun, which were characterized as the deepest locations. These variations in discard ratios underscore the complex relationship between discard practices and location-specific factors, including depth and the presence of Lessepsian species in the Mediterranean. The higher discard ratios observed in the southern region, specifically Güllük, can be attributed to a combination of factors, including depth and biodiversity. Additionally, the influence of Lessepsian migration may also be a significant contributing factor for Güllük, where the number of Lessepsian migrant species and their quantities were greater than in other locations. This observation aligns with the findings of Sartor et al. (2003), who reported a decrease in species diversity with increasing depth. Consequently, it can be emphasized that depth and biodiversity, which are interrelated parameters, exert a considerable influence on the composition and patterns of discarding in the Aegean Sea.

In addition to regional considerations, the spatio-temporal approach to understanding discarding encompasses as a crucial factor seasonality, which, in combination with depth, is reported to significantly impact the distribution and abundance of species, consequently influencing the formation and composition of discards (Pillai et al. 2014). Furthermore, Gücü (2012) emphasized the role of both the month and depth as influential factors affecting discard ratios, particularly in the Levant Sea. Notably, the highest discard values were documented during the months of August to October, highlighting the temporal dimension of discarding practices in this region. Contrary to Damalas et al. (2018), our study identified a significant seasonality effect on DPUE and revealed substantial variations in discard ratios across seasons, the most significant differences being observed between winter and summer. This difference in discarding practices can also be linked to long haul durations and the majority of unmarketable species in the catch composition, as trawlers are compelled to operate in deeper waters during the summer in Türkiye because of coastal restrictions. This scenario serves as a noteworthy illustration of how management regulations can directly impact discarding practices. It highlights how seasonal and regulatory factors interact to shape the dynamics of discards in the region, emphasizing the intricate relationship between environmental and management influences on fishing activities. Discard regulations within the Turkish fishery management system differ from those outlined in the landing obligation of the reformed Common Fisheries Policy, primarily because Türkiye is not a member of the European Union. As a non-member of the European Union, Türkiye has its own distinct set of regulations and policies governing discarding practices within its fisheries management framework. Turkish skippers are not obligated to land the discarded catch, even when the species involved have special status. Instead, they are required to report the quantity of the discarded portion in the vessel's logbook. While vessel logbooks are subject to periodic checks by the relevant authorities, obtaining precise and reliable data on the composition and quantities of discards from these records is challenging because of the lack of a standardized and consistent approach.

A common feature of Mediterranean bottom trawl fisheries is the practice of retaining all marketable individuals, regardless of specific target species. This behaviour is largely a response to the high species diversity prevalent in the region, which in turn results in a considerable volume of discards. The primary reason for these discards can be traced back to the lack of commercial value associated with certain species that are captured, as emphasized by Sartor et al. (2003). The diversity of the Mediterranean marine environment, the multi-gear, multispecies character of the fishery and huge cultural variety along the Mediterranean coast are reported to influence discarding patterns in the basin (Tsagarakis et al. 2017). Although we have quite enough knowledge on the formation processes and composition of discards in the Mediterranean, discard data are still one of the essential components of ecosystem-based fisheries management, especially for multispecies trawl fishery. Therefore, discard studies must ensure continuity in all parts of the Mediterranean. At this juncture, data from non-European Union countries are of utmost importance, especially in regions where the Common Fisheries Policy and its associated regulations have not been implemented. Therefore, the findings of the current study will serve as a valuable complement to our understanding of the eastern Mediterranean, contributing to a more comprehensive perspective on fisheries and discarding practices in areas beyond the scope of European Union regulations.

The results of the current study have unveiled the presence of substantial quantities of discards within the total catch, accompanied by a high level of species diversity within the discarded fraction. Consequently, the Turkish side of the Aegean Sea, recognized as one of the most heavily exploited fishing zones in the Turkish seas, warrants ongoing, long-term monitoring to assess the impact of discards on marine communities. To establish an effective discard management strategy, the adoption of a fully documented fisheries approach is essential. This involves not only implementing technical measures but also incorporating innovative tools and technologies such as electronic monitoring. Consequently, considering the magnitude and effects of unwanted catches in the Aegean Sea, discard characteristics (species composition, DPUE values, discard ratio, etc.) of trawl fishery in the area should be seriously considered during decision making. Management actions could take into consideration the implementation of spatial and temporal closures, closing the fisheries in those areas and periods of the year where and when high discard ratios are observed. The outcomes of future studies on discards play a pivotal role in facilitating the sustainable management of the region's biological resources.

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AUTHORSHIP CONTRIBUTION STATEMENT

Ozan Soykan: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft.

Tevfik Ceyhan: Conceptualization, Formal analysis, Methodology, Writing – review & editing.

REFERENCES

Andy S. 2017. rnaturalearth: World Map Data from Natural Earth. R package version 0.1.0. https://CRAN.R-project.org/package=rnaturalearth

Cerim H., Yapici S., Reis İ., Ates C. 2022. Southern Aegean Sea Trawl Fishery; Discard Ratio and Mortality of Targeted Species. Thalassas 38: 157-169. https://doi.org/10.1007/s41208-021-00388-z

Coll M., Piroddi C., Steenbeek J., et al. 2010. The biodiversity of the Mediterranean Sea: estimates, patterns, and threats. PLoS ONE 5: e11842. https://doi.org/10.1371/journal.pone.0011842

D'Onghia G., Carlucci R., Maiorano P., et al. 2003. Discards from deep-water bottom trawling in the eastern-central Mediterranean Sea and effects of mesh size changes. J. Northwest Atl. Fish. Soc. 31: 245. https://doi.org/10.2960/J.v31.a19

Damalas D., Ligas A., Tsagarakis K., et al. 2018. The "discard problem" in Mediterranean fisheries, in the face of the European Union landing obligation: the case of bottom trawl fishery and implications for management. Mediterr. Mar. Sci. 19: 459-476. https://doi.org/10.12681/mms.14195

Despoti S., Stergiou K.I., Machias A., et al. 2021. Assessing the spatial distribution of five non-commercial fish species in the Aegean Sea (Greece, eastern Mediterranean Sea) based on discards data. Reg. Stud. Mar. Sci. 44: 101736. https://doi.org/10.1016/j.rsma.2021.101736

Despoti S., Stergiou K.I., Tserpes G., et al. 2024. Can we gain new knowledge from the discarded fraction of the low-price commercial species of the bottom trawl fishery? An insight into the Eastern Mediterranean (Aegean Sea, Greece). Hydrobiologia 851: 129-146. https://doi.org/10.1007/s10750-023-05318-z

Dunn P.K., Smyth G.K. 2005. Series evaluation of Tweedie exponential dispersion model densities. Stat Comput. 15: 267-280. https://doi.org/10.1007/s11222-005-4070-y

Dunnington D. 2021. ggspatial: Spatial Data Framework for ggplot2. https://paleolimbot.github.io/ggspatial/. Accessed online 23 September 2021.

Edelist D., Sonin O., Golani D., et al. 2011. Spatiotemporal patterns of catch and discards of the Israeli Mediterranean trawl fishery in the early 1990s: ecological and conservation perspectives. Sci. Mar. 75: 641-652. https://doi.org/10.3989/scimar.2011.75n4641

EU 2013. Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No. 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No. 2371/2002 and (EC) No. 639/2004 and Council Decision 2004/585/EC. OJ L 354, 28.12.2013, 22-61. Available: https://eur-lex.europa. eu/legal-content/EN/TXT/?uri=celex%3A32013R1380.

Foster S.D., Bravington M.V. 2013. A Poisson-Gamma model for analysis of ecological non-negative continuous data. Environ. Ecol. Stat. 20: 533-552. https://doi.org/10.1007/s10651-012-0233-0

Gökçe G., Saygu I., Eryaşar A.R. 2016. Catch composition of trawl fisheries in Mersin Bay with emphasis on catch biodiversity. Turk. J. Zool. 40: 522-533. https://doi.org/10.3906/zoo-1505-35

Gücü A.C. 2012. Impact of depth and season on the demersal trawl discard. Turkish J. Fish. Aquat. Sci. 12: 817-830.

Hair J.F., Black W.C., Babin B.J., Anderson R.E. 2010. Multivariate Data Analysis. 7th Edition, Pearson, New York.

Hastie T.J., Tibshirani R.J. 1990. Generalized Additive Models, Monographs on Statistics and Applied Probability, Vol:9, Chapman & Hall 43, UK.

Kelleher K. 2005. Discards in the World's Marine Fisheries: An update. FAO Fisheries and Technical Paper, No: 470, Rome.

Keskin Ç., Ordines F., Ates C., et al. 2014. Preliminary evaluation of landings and discards of the Turkish bottom trawl fishery in the northeastern Aegean Sea (eastern Mediterranean). Sci. Mar. 78: 213-225. https://doi.org/10.3989/scimar.03942.30B

Maeda E.E., Mäntyniemi S., Despoti S., et al. 2017. A Bayesian model of fisheries discards with flexible structure and priors defined by experts. Ecol. Model. 366: 1-14. https://doi.org/10.1016/j.ecolmodel.2017.10.007

Machias A., Vassilopoulou V., Vatsos D., et al. 2001. Bottom trawl discards in the northeastern Mediterranean Sea. Fish. Res. 53: 181-195. https://doi.org/10.1016/S0165-7836(00)00298-8

Montgomery D.C., Peck E.A., Vining G.G. 2015. Introduction to Linear Regression Analysis. John Wiley & Sons, Hoboken.

Pedersen E.J., Miller D.L., Simpson G.L. et al. 2019. Hierarchical generalized additive models in ecology: an introduction with mgcv. PeerJ 7: e6876. https://doi.org/10.7717/peerj.6876

Pillai S.L., Kizhakudan S.J., Radhakrishnan E.V., et al. 2014. Crustacean bycatch from trawl fishery along North Tamil Nadu coast. Indian J. Fish. 61: 7-13.

R Development Core Team. 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org

Roda M.A.P., Gilman E., Huntington T., et al. 2019. A third assessment of global marine fisheries discards. Food and Agriculture Organization of the United Nations, Technical Paper 633, Rome.

Sartor P., Sbrana M., Reale B., et al. 2003. Impact of the deep sea trawl fishery on demersal communities of the northern Tyrrhenian Sea (Western Mediterranean). J. Northwest Atl. Fish. Sci. 31: 275-284. https://doi.org/10.2960/J.v31.a21

Simpson G.L. 2022. gratia: Graceful 'ggplot'-based graphics and other functions for GAMs fitted using 'mgcv'. https://gavinsimpson.github.io/gratia. Accessed online 23 September 2021.

Soykan O., Bakir K., Kinacigil H.T. 2019. Demersal trawl discards with spatial and bathymetric emphasis in the Turkish coast of the Aegean Sea. Mar. Biol. Res. 15: 113-123. https://doi.org/10.1080/17451000.2019.1576902

Stergiou K.I. 1999. Effects of changes in the size and shape of codend on catch of Aegean Sea fishes. ICES J. Mar. Sci. 56: 96-102. https://doi.org/10.1006/jmsc.1998.0421

Stergiou K.I., Christou E.D., Georgopoulos D., et al. 1997. The Hellenic Seas: Physics, chemistry, biology and fisheries. Oceanogr. Mar. Biol. 35: 415-538.

Stergiou K.I., Economou A., Papaconstantinou C., et al. 1998. Estimates of discards in the hellenic commercial trawl fishery. Rapp. Comm. Int. Mer Medit. 35: 490-491.

Tiralongo F., Mancini E., Ventura D., et al. 2021. Commercial catches and discards composition in the central Tyrrhenian Sea: a multispecies quantitative and qualitative analysis from shallow and deep bottom trawling. Mediterr. Mar. Sci. 22: 521-531. https://doi.org/10.12681/mms.25753

Tsagarakis K., Palialexis A., Vassilopoulou V. 2014. Mediterranean fishery discards: Review of the existing knowledge. ICES J. Mar. Sci. 71: 1219-1234. https://doi.org/10.1093/icesjms/fst074

Tsagarakis K., Carbonell A., Brci C. J., et al. 2017. Old Info for a New Fisheries Policy: Discard Ratios and Lengths at Discarding in EU Mediterranean Bottom Trawl Fisheries. Front. Mar. Sci. 4: 99. https://doi.org/10.3389/fmars.2017.00099

Tsagarakis K., Zupa W., Ligas A., et al. 2024. Factors affecting the variability of discards in Mediterranean bottom trawl fisheries. Fish. Res. 274: 106979. https://doi.org/10.1016/j.fishres.2024.106979

Turkstat. 2014. Fishery Statistics [online database]. Available: https://biruni.tuik.gov.tr/medas/?kn=97&locale=en

Turkstat. 2024. Fishery Statistics. [online database]. Available: https://data.tuik.gov.tr/Bulten/Index?p=Su-Urunleri-2021-45745

Tweedie M.C.K. 1984. An index which distinguishes between some important exponential families. In: Applications and New Directions: Proceedings of the Indian Statistical Institute Golden Jubilee International Conference. 579: 579-604.

Wei T., Simko V. 2021. R package ‘corrplot’: Visualization of a Correlation Matrix. (Version 0.92), https://github.com/taiyun/corrplot

Wickham H., Averick M., Bryan J., et al. 2019. Welcome to the tidyverse. JOSS, 4(43): 1686. https://doi.org/10.21105/joss.01686

Wood S.N. 2003. Thin plate regression splines. Journal of the Royal Statistical Society. J. R. Stat. Soc. Ser. B Methodol. 65: 95-114. https://doi.org/10.1111/1467-9868.00374

Wood S.N. 2004. Stable and efficient multiple smoothing parameter estimation for generalized additive models. JASA 99: 673-686. https://doi.org/10.1198/016214504000000980

Wood S.N. 2017. Generalized additive models: An introduction with R, second edition. CRC Press, UK. https://doi.org/10.1201/9781315370279

Wood S.N., Pya N., Säfken B. 2016. Smoothing Parameter and Model Selection for General Smooth Models. JASA, 111: 1548-1563. https://doi.org/10.1080/01621459.2016.1180986

Yemişken E., Dalyan C., Eryilmaz L. 2014. Catch and discard fish species of trawl fisheries in the Iskenderun Bay (Northeastern Mediterranean) with emphasis on lessepsian and chondricthyan species. Mediterr. Mar. Sci. 15: 380-389. https://doi.org/10.12681/mms.538