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RESEARCH PAPER

Temporal-Spatial Influences on Atlantic Bluefin Tuna CPUE in Recreational Fishery in the Aegean Sea: A Generalized Additive Model Approach

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Abstract

The *Thunnus thynnus*, a sought-after fish in recreational fishing, demands sustainable management due to its migratory nature. However, the lack of data on the impact of recreational fishing hampers understanding. This study aims to address this gap using Catch Per Unit Effort (CPUE) data from fishing contests on the Urla Peninsula (2016-2022). Findings revealed a yearly influence on CPUE, with the mean at 5.56±0.49 Kg·day^{-1}. The peak was in 2018 with 13.98 Kg·day$^{-1.}$ Individual catches ranged from 305 to 10.45 Kg. 'Catch' was 21 times more prevalent than 'Catch and Release.' More catches occurred in the southern area, possibly due to tuna fattening cages. The study showed a yearly influence, but the dataset is insufficient to fully understand the environmental variables' impact. Despite the limitations, the potential of this data as a future benchmark for recreational fishing efforts is significant.

Introduction

The Atlantic Bluefin tuna (ABFT) has been analyzed and managed two different stocks. The status of the stocks and their regulatory politicizes are carried by the International Commission for the Conservation of Atlantic tunas (ICCAT). According to the latest review report on the stock status of the Eastern Atlantic Bluefin Tuna (Mediterranean stock) the stock its's not overfished and the models provides information about the increasing od abundance and is likely to continue to increase given the recent patterns of fishing mortality (ICCAT, 2022). However, the committee remains precatory about the possibility of increase the TAC of the previous years. The main reason is the aware of ongoing, unqualified, IUU (Illegal unreported and unregulated fishing) catches that represent a serious impediment to being able to determine the productivity of the stock. Already the "catch-only" predictive models can induce to poor and biased estimates of stock status (Ovando et al., 2022) information gaps from IUU generate even more challenge in the efforts at effective and sustainable management.

The IUU affected to all species in the Mediterranean Sea, and this activity not only includes the fishing vessels. The violation of the recreational fishing legislation or even the lack of regulation and control of it, can be categorized as a IUU fishing (Miller & Sumalia, 2016). In the FAO Technical Guidelines for responsible fisheries nº 13 Recreational Fisheries published in 2012 (FAO, 2012), the scientific commission defined recreational fishing as this: "Recreational fishing is thus defined as fishing of aquatic animals (mainly fish) that do not constitute the individual's primary resource to meet basic nutritional needs and are not generally sold or otherwise traded on export, domestic or black markets (EIFAC, 2008; Mike & Cowx, 1986)". However, when recreational fishing is defined in the socio-economic context of the Mediterranean Sea, there are many nuances that make quantifying this activity especially difficult. Therefore, attempting to estimate the impact of recreational fishing on the stock of our oceans is a complex challenge. It is estimated that almost 11% of the world's population (10.6±6.1) is engaged in this activity (Arlinghaus & Cooke, 2009) This percentage obviously varies according to the country, but in the case of the Mediterranean, recreational fishing is an important source of entertainment and tourism, generating strong economic but also environmental impacts. The GFCM report of 2010 estimates that more than 10% of the total fishery in the Mediterranean was composed of amateur fishery (GFCM, 2010). In Türkiye, as in many other Meditarranean countries, the fishing licenses are not mandatory, however for the bluefin tuna caught, it is obligatory to have a Tuna Catch Document (e-BCD) issued by the provincial/distract directorates. This documentation agrees with the action measures recommended by ICCAT. The scope and economic significance of charter fishing activities have beet studied in the Aegean sea for small scale fisheries species (Ünal et al., 2010; Tunca et al., 2016, Öndes et al 2020) but any study is focused yet in fishing stock impact of the ABFT recreational fishing.

Assignments of the CPUE to fisheries have been utilized to standardize catch and abundance indices for various species. This index has evolved by incorporating different factors to estimate effort, leading to the development of advanced models and standardizations of CPUE in both the Mediterranean Sea (Karakulak & Ceyhan, 2024) and the Atlantic Ocean (Rodriguez-Martin et al., 2003) for ABFT. Despite concerns within the scientific community regarding the CPUE index's reliability, it has been demonstrated as an effective tool for estimating daily bluefin tuna catches in traps (Addis et al., 2012). Furthermore, CPUE based on daily catches has been employed to estimate the duration of spawning seasons (Gordoa, 2010). While there is ample research on CPUE standardization in commercial fishing, there is a dearth of studies on CPUE standardization in recreational fisheries.

The primary objective of this study is to review the recreational fishing of Thunnus thynnus in the Aegean Sea, on the Turkish coast of Izmir. With that propose, new study tools based on the alternative data has been incorporated. Secondary objectives may be (**a**) determine the total CPUE of the fishing contest and the CPUE based on other factors such as the year, the fishing zone and the contest. (**b**) Generate predictive models with the CPUE data and other determinant factors such as the environmental data (sea surface temperature and Chlorophyll a). (**c**) Analyze the By-catch related with the ABFT catch in the sportive contests.

Materials and Methods

Study Area

The study area of this project is in the Aegean Sea, in the Eastern area of the Mediterranean Sea. More specifically, in the Urla Peninsula (Urla Yarımadası) in the province of Izmir, Türkiye. It has been registered the presence of ABFT on the Turkish coast since the prehistory (Di Natale, 2015). The bluefin tuna transit these waters following the banks of small pelagic along the coast and attracted by aquaculture installations, especially the tuna fattening cages (Dempster et al., 2002; Özgül et al., 2023). In our study area, two sportive fishing contests are held around the towns of Çesme, Teos and Alaçati and generate fishing areas A, B and C respectively. As we can appreciate in the Figure 1, while the Big Fish competitions are located in areas A and B,

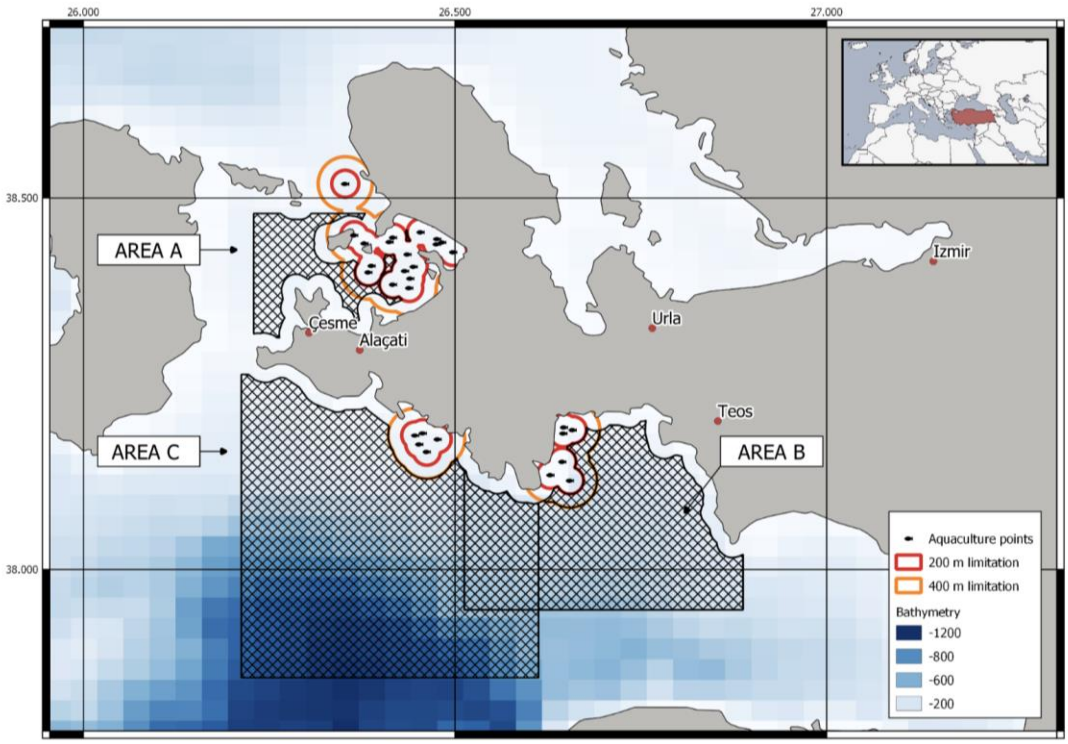

Figure 1. Study area.

the Tuna Masters competitions occupy areas B and C. Notice that the area B, which hosts two competitions, varies slightly according to the restrictions and rules of each contest. The main constraints on the fishing area are proximity to the aquaculture cages. Tuna Masters contest imposes a limit of 400 meters away from the sea catches meanwhile the Big Fish enforces only 200 meters.

Data Set Adaptation and Statistical Analysis

Catch and effort data for the Recreational Atlantic Bluefin Tuna (ABFT) fishery were obtained from a combination of logbooks submitted by boats participating in contests and field surveys conducted between 2016 and 2022. The dataset includes information on the current date (day, month, and year), the number of fishes caught by each vessel, and the total catch. Additionally, during one of the contests, the fishing area was expanded to two areas simultaneously, resulting in the creation of a fourth fishing area denoted as A+B. Sea surface temperature (SST) and chlorophyll concentration (mg/m3) data for this study were retrieved from the European Union Copernicus Marine Service Information (Cossarini et al. 2021; Nardelli et al., 2013 and Teruzzi et al., 2021). The contests were divided into two parts: Catch and Catch and Release. In the Catch section, weight data of the ABFT were recorded. In the Catch and Release section, only length data were recorded for each specimen. To calculate the weight of each specimen in the Catch and Release section, the length-weight equation proposed by Rodriguez-Marin et al. (2015) was employed.

The CPUE was calculated from three parameters as below for each fishing vessel:

$$CPUE = B\ D^{-1} \tag{1}$$

Where B is the biomass of ABFT and D is fishing day.

The CPUE is represented as total catch (Kg) of each fishing day. A better approach it would be to express it using the number of teams or participants, but the exact number of participants/team is not specified in the original database. Some boats only allow two participants, while others can accommodate up to seven. Also, the total members of the team can change in the different years.

The effect of variables on CPUE was examined by means of the Generalised Additive Modelling (GAMs) techniques (Hastie & Tibshirani, 1987). The additive models and their generalisations make available to use many nonparametric models which are essential in regression analysis when the linearity assumption does not engage well (Friedman &Stuetzle, 1981; Hastie & Tibshirani, 1987; Amodio et al., 2014). Additionally, the advantages (i.e. interpretability, flexibility and regularisation) of GAM, make general additive models more selectable for this thesis. Tweedie family and log link function (Tweedie, 1984; Dunn and Smyth, 2005; Wood et al., 2016) were used to examine various predictor variables (Year, SST, Chlorophyll-a, Longitude and Latitude) on the CPUE. Tweedie distributions are the one family of distributions that include gamma, normal, Poisson and their combinations, despite being based partly on the Poisson family. In this thesis, the variance power (p) was chosen 1.001 in the model. Restricted maximum likelihood (REML) was also applied as a maximum likelihood-based smoothness selection procedure. The maximum degrees of freedom for each smoothing term were set to 7,7,9,3 for Years, SST, Chlorophyll-a and spatial data, respectively:

$$CPUE \sim a+s(Y,\ k=7)+S(SST,\ k=7)+S(Ca,k=9)+\ te(lon,lat,k=3)\ +e \tag{2}$$

Where, a is the intercept, Y isYear, SST is Sea Surface Temperature, Ca is Chlorophyll- a ,lon is longitude, lat is latitude, s indicates the smoother function of the corresponding independent variable, te is the tensor product smooths. and e is a random error term.

The test of whether the basis dimension for a smooth is adequate (Wood, 2017) were done by k-index (the estimate of the residual variance based on differencing residuals) and p- value, computed by simulation. A log link function was assumed and deficiencies of the fitted model were diagnosed by QQ plot of the deviance residuals and means of randomised quantile residual plots (Foster & Branvington 2013; Pedersen et al., 2019). Statistical inference was based on the 95% confidence level. The model fitting was accomplished using the “mgcv” library (Wood, 2003; 2004; 2011; 2017; Wood et al., 2016) The “tidyverse” (Wickham et al., 2019), “gratia” (Simpson, 2023), “ggspatial” (Dunnington, 2022), rnaturalearth (Andy, 2017), were also required under the R language environment (R Core Team, 2022). Finally, the analysis of the by-catch data involved calculating the total weight caught for each species. Subsequently, the ratio was determined as a percentage of this total, and a rate was assigned to each fish.

Results

A total of 24 fishing days were analysed, estimating a total of 96 fishing hours. The individual weights of ABFT were recorded from 305 to 10.45 Kg (Total mean of 50.47±36.98 Kg). A total of 1041 CPUE data was calculated. The values were between 0 and 117 Kg·day^{-1} and the mean CPUE was 5.56±0.49 Kg·day^{-1} The maximum CPUE was recorded in 2018 (13.98 Kg·day^{-1}) and the minimum CPUE was recorded in 2017 (2.86 Kg·day^{-1}). The year 2018 was exceptionally high but also showed an elevated dispersion (sd) reached with the other years (34.07). This turbulence can be easily observed in Figure 2 associated with the year CPUE data. This year was also the year in which the hugest ABFT was caught, the specimen of 305 Kg.

The analysis of the type of catch (Figure 3) shows that the most popular methodology is the Catch (994 samples) against the Catch And Release (47 samples); this result shows that Catch is 21 times more frequent than Catch And Release. The CPUE of Catch (4.12±13.37 Kg·day-1), is lower than the Catch and Release (36.06±25.95 Kg·day^{-1}).

The fishing zone with major CPUE is the A+B zone with 14.53±21.44 Kg·day^{-1} followed by zone B (6.49±17.17 Kg·day^{-1}), zone C (3.06±12,52 Kg·day^{-1}) and zone A (4.39±11,63 Kg·day^{-1})(Figure 4).

The diagnostic information about the fitting procedure and results show that the basis dimensions used for smooth terms were adequate (Table 1). The QQ plot of the deviance residuals and deviance residuals vs. fitted plot of the applied GAM model show that any outstanding feature that would suggest inappropriateness of the fitted model (Figure 5a). Figure 5a also showed that the model distributional assumptions were met. Furthermore, the response data were independent, so the residuals appeared approximately as well (Figure 5b). So, the model fitted very well and there were no large confidence intervals.

The analysis of the deviance table indicated that the year was significant (Table 2) as variable. In addition to this, the high confidence intervals in the beginning years, the line was observed as undulant (Figure 6). Despite occurring the high confidence intervals in some parts of plots, the lines were seen as approximately stable in Figure 7a for SST and definitely stable for chlorophyll-a in Figure 7b. These figures also bore out Table 2, as well. For the map representation of CPUE in the area, it can be observed the high effect on CPUE in contrast to the blue area, placed in the southern part of the peninsula (Figure 8) Therefore, the results showed that the year was just a major explanatory factor. Although the SST, spatial data and chlorophyll-a had little influence on the CPUE.

In the analysis of by-catch species there were 6 recorded species and the rates amount varied between 1.75% and 66.83% (Figure 9). The most captured by-catch species was Xiphias gladius (66.83% and 160 Kg), 3.26 times more frequent than the second one, Thunnus alalunga (20.51% and 49.1 Kg).

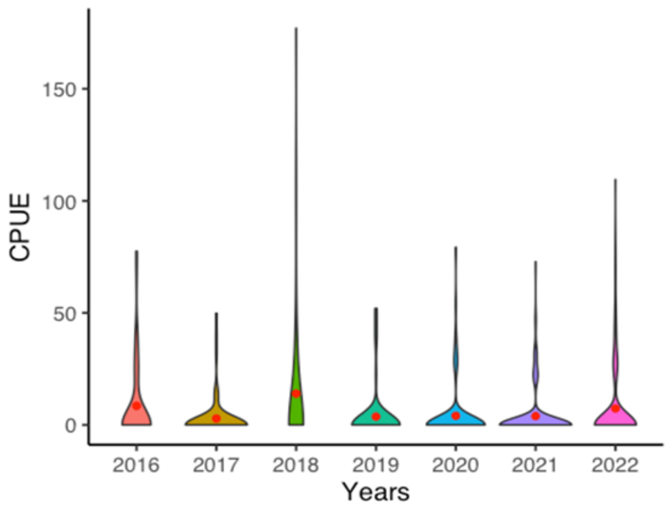

Figure 2. Annual CPUE (Kg·day^{-1}) values for the recreational ABFT fishery in Türkiye.

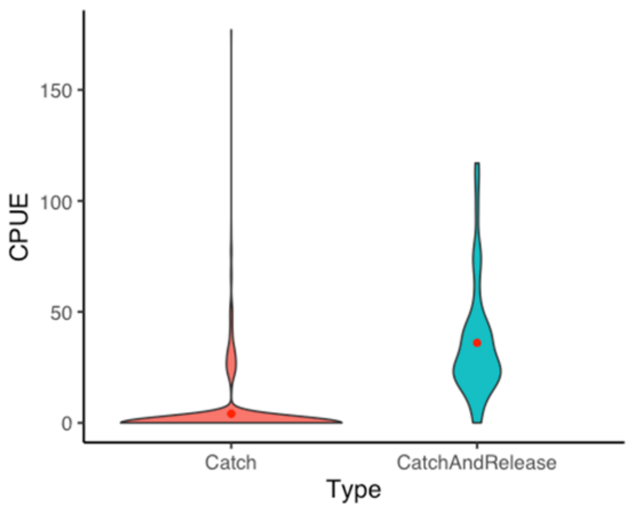

Figure 3. Violin plot representing the CPUE (Kg·day^{-1}) depending on the type of catch: Catch or Catch and Release.

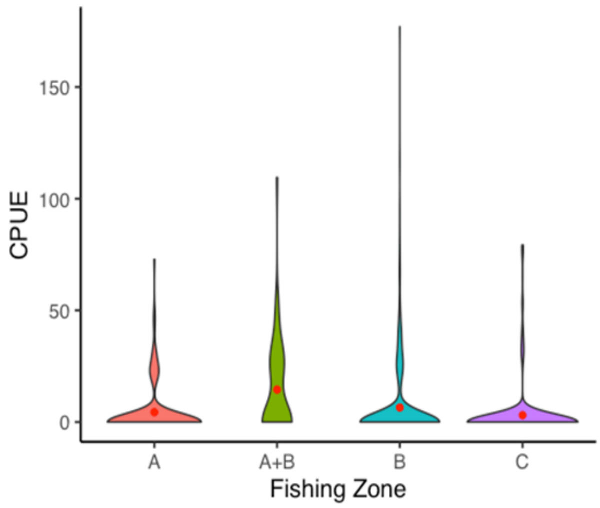

Figure 4. The CPUE (Kg·day^{-1}) values of Turkish recreational ABFT fishery by the fishing zones delimited in the study area.

Table 1. Result of the basis dimensions of GAM*

Factor	k	edf	k-index	p-value
s (year)	6.00	3.98	1.08	0.80
s (Chlorophyl-a)	6.00	3.28	1.10	0.93
s (SST)	8.00	1.00	1.08	0.83
te (lon,lat)	8.00	2.00	0.92	0.17

*(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.)

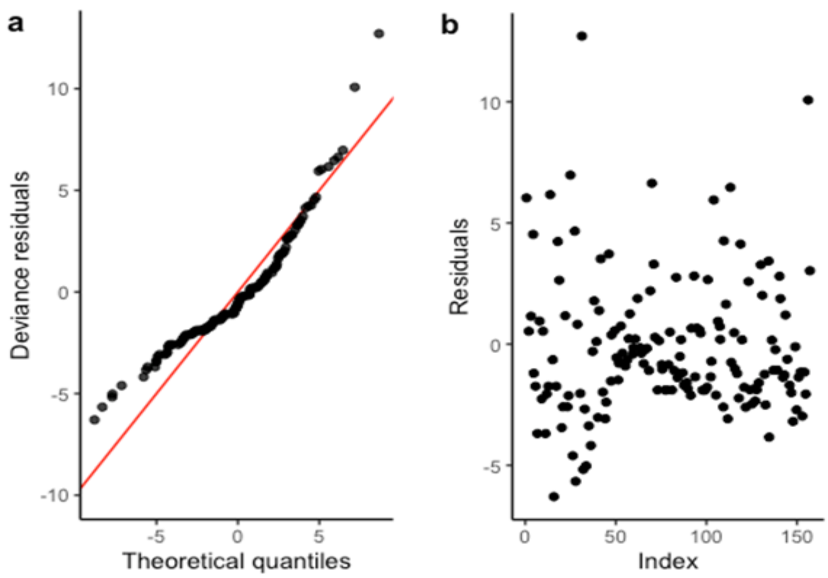

Figure 5. (**a**) QQ-plot of residuals (black). The red line indicates the 1–1 line. (**b**) means of randomised quantile residuals.

Table 2. This is a table. Tables should be placed in the main text near to the first time they are cited.

Factor	df	F	p-value
s (year)	6.00	2.894	<0.05
s (Chlorophyl-a)	3.505	0.387	0.79
s (SST)	1.004	0.018	0.89
te (lon,lat)	2.000	1.247	0.29

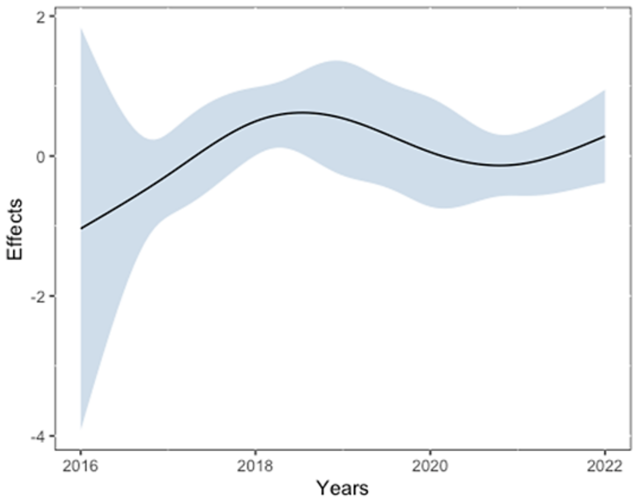

Figure 6. GAM estimated effect of Years on CPUE

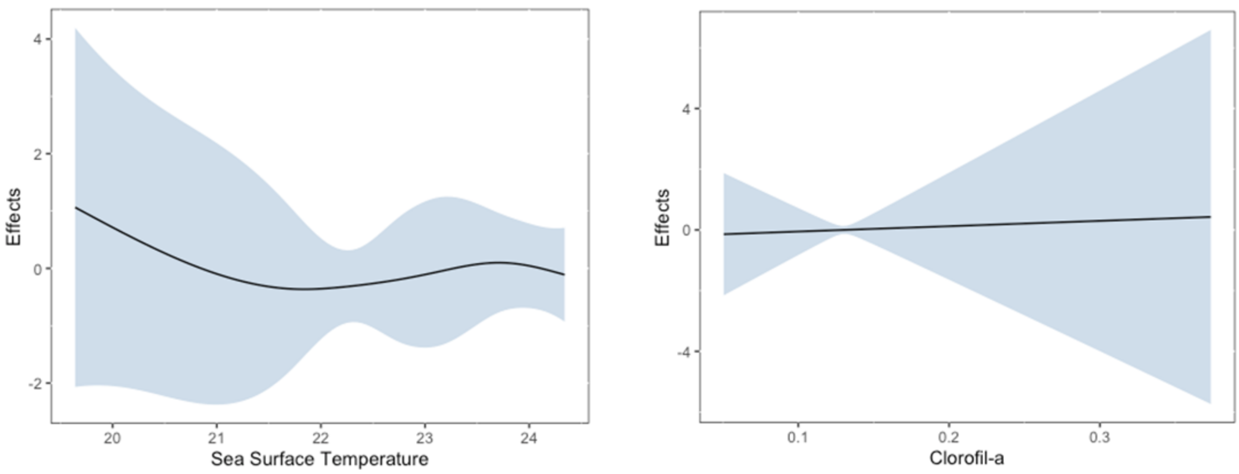

Figure 7. (**a**) GAM estimated effect of SST on CPUE data; (**b**) GAM estimated effect of Chlorophyll-a on CPUE data.

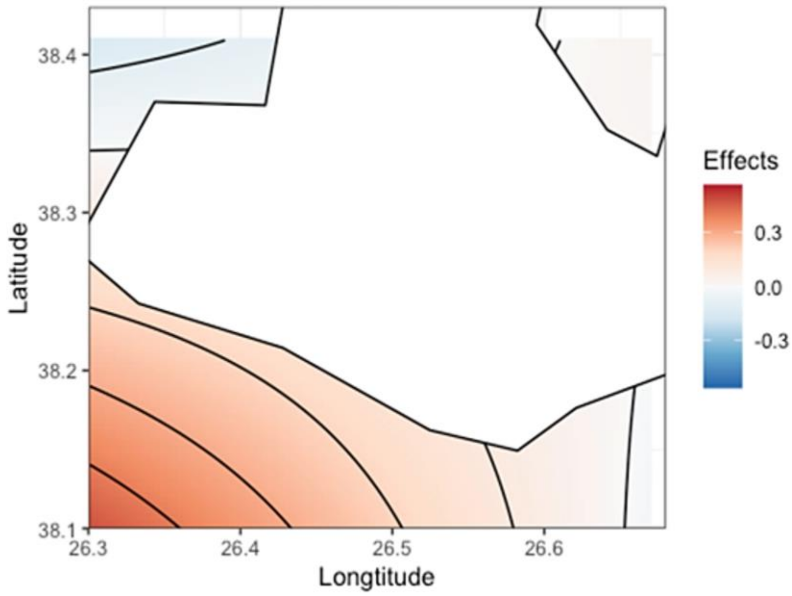

Figure 8. GAM estimated effect of Years.

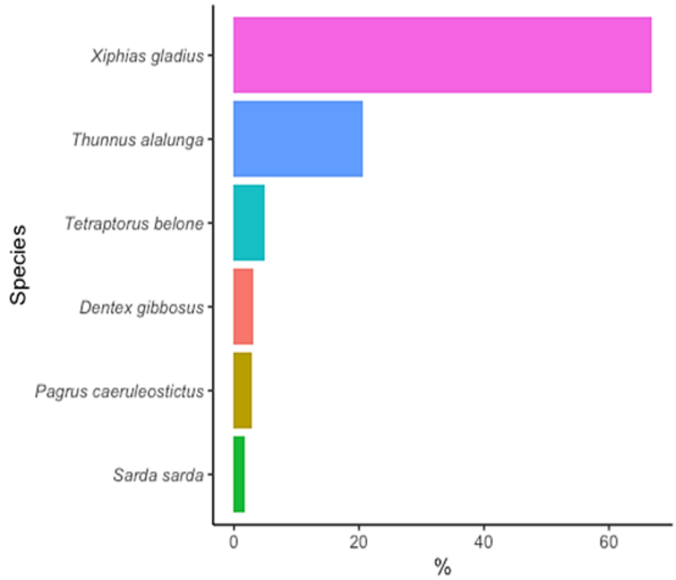

Figure 9. Species ratios in total by-catch amount.

Discussion

The catches of ABFT in the Mediterranean have exhibited significant historical variability. While the stock was officially labeled as overfished in (ICCAT, 2017), there has been a notable increase in ABFT abundance since the launch of the ICCAT bluefin tuna recovery plan in the same year. This positive trend led to the Scientific Committee of ICCAT (SCRS) recommending a shift from a recovery plan to a more comprehensive management plan. One major concern stemming from the Recovery Plan for bluefin tuna in the eastern Atlantic and the Mediterranean is the considerable reduction in fishing capacity observed in small-scale fleets. The implementation of this plan has significantly impacted these fleets, specifically in terms of diminishing their fishing capacity (ICCAT, 2021). In this study, our objective was to identify the influences of various factors—such as the year, fishing zone, and environmental variables like sea surface temperature and Chlorophyll a—on the Catch Per Unit Effort (CPUE) of recreational ABFT fishery. This research is crucial because recreational fishing remains globally significant and should be considered in fisheries management plans by Regional Fisheries Management Organizations (RFMOs). Beyond its economic importance as a food source, the recreational fishery's ongoing relevance emphasizes the need for comprehensive management strategies.

The model results, when analyzed over the years, reveal a consistent upward trend, with a mean CPUE of 5.56±0.49 $Kg{\cdot}day^{-1}$. However, caution is warranted in interpreting these findings. The CPUE per year, depicted in the plot, underscores considerable variability within each year, and notably, the most recent years don't align with periods of greater abundance. This fluctuation is mirrored in the abundance indices reported in ICCAT documents. It's important to note that our data, being on a smaller scale, cannot be directly compared with estimates for the entire Mediterranean stock (ICCAT, 2021). Additionally, the discrepancy in the start times of the records for both contests has likely contributed to this variation and interannual variability. This distinction is pivotal for a nuanced interpretation of the yearly results. Specifically, data for 2021 and 2022 have been aggregated, while the data for the preceding years are presented individually. This consideration ensures a more accurate understanding of the trends and avoids potential misinterpretations due to differing aggregation methods.

Other studies shift their focus towards assessing the impact of recreational vessels stationed along coastlines rather than emphasizing specific sporting contests. An illustrative instance involves landing controls implemented to examine the recreational fishing impact on ABFT in Italy, revealing an average CPUE of 64.27 kg per vessel. The primary finding of this study underscores the challenging nature of monitoring tuna sport fishing activities, particularly noting the inefficiency of current methods such as "TR forms" or ABFT catch declarations. A proposed solution is the enhancement of more effective monitoring or landing control systems, as suggested by Di Natale et al. (2005). Moreover, Tracey et al (2022) mentioned another example pertains to surveys employed in estimating the recreational fishing effort and the average fish weight caught for Southern Bluefin Tuna (Thunnus maccoyii) in Australia This study emphasizes the imperative need to study each area or region separately to facilitate the convergence towards better and tailored management regulations for recreational fisheries. The diverse approaches showcased in these studies underscore the multifaceted nature of recreational fishing impacts, advocating for comprehensive and region-specific management strategies.

The ABFT holds a prominent ecological position, and longitudinal observations indicate its predominant occupancy in surface and subsurface regions correlated with the stratification of the thermocline (Tudela et al., 2011). The model in this study, incorporating the Sea Surface Temperature (SST) factor, has revealed a plausible correlation with the spatial distribution of ABFT up to 22°C. Notably, other ecological variables lack substantial representation in this model, suggesting that SST may play a pivotal role in influencing the habitat preferences of ABFT. Further investigation and consideration of additional ecological factors are warranted to enhance the comprehensiveness of our understanding. Regarding the bycatch species, there is a high selectivity observed in this fishing contest due to the species composition. The anatomy and size of the Swordfish make it the first bycatch species, followed by the most common and similar tunid in the area, the Albacore tuna.

In general, the predominant articles and studies focused on recreational fishing, encompassing not only the Scombridae family but also extending to broader contexts, consistently underscore the necessity to establish comprehensive monitoring and management mechanisms. These initiatives are vital for assessing the impact of recreational fishing on both fish stocks (Öndes et al., 2020; Lewin et al., 2019) and the environment (Pranovi et al., 2015). To advance our understanding further, future studies should incorporate additional variables such as bait type, soak time, and the number of hooks deployed per boat in the context of recreational ABFT fishery in the Mediterranean. The inclusion of these variables would contribute to a more nuanced and detailed comprehension of the dynamics surrounding ABFT recreational fishing, aiding in the formulation of more effective management strategies. Additionally, other countries as the UK have generate an interesting program known as CHART with the collaboration of the administration and the recreational fisheries community to consolidate a data recompilation and target strategy during the fishing season of the ABFT (Phillips et al 2022).

In conclusion, the main ideas of this paper are that the consistency on the data registration must be consistent and coherent to guarantee better results; moreover, the implication of the administration and the scientific community can significatively improve the collected information: georeferenced data, maturity data recompilation and targeting can be implemented during the contests. Other factors as the effect of the distance to the coast and sea cages and the spawners can be studied if the implementation of this data is achieved. Finally, more information and studies about the impact of the recreational fishing are needed to implement the management plans and the ecological information about the species.

Ethical Statement

Not applicable.

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The authors did not receive fundigs to this study.

Author Contribution

First Author: Conceptualization, Data Curation, Writing -original draft, Investigation; Second Author: Data Curation, Formal Analysis, Methodology, Visualization and Writing -review and editing; Third Author:, Resources, Writing -review and editing, Supervision.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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