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UPDATE ON THE BLUEFIN TUNA CATCHES FROM THE TUNA TRAP FISHERY OFF SOUTHERN PORTUGAL (NE ATLANTIC) BETWEEN 1998 AND 2016, WITH A PRELIMINARY CPUE STANDARDIZATION

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SUMMARY

This paper updates information previously presented on the bluefin tuna catches from a tuna trap fishery operating off the southern coast of Portugal (Algarve). Trends of intra- and inter-annual catches were analysed. Since 2012 the Portuguese quota has been reached while the number of days required to reach the quota have been decreasing. The average size of fish has been significantly increasing with progressively a higher proportion of large males being captured. The trend for the nominal CPUE calculated for a single trap shows relatively low and flat period between 1998 and 2008, followed by a steep increase in the more recent years. A preliminary CPUE standardization was carried out with a Tweedie GLM using year and month (seasonal) effects. The standardized CPUE followed in general the nominal CPUE trends, with relatively low values and a flat period until 2008, followed by a steep increase and much higher values in the more recent years. These results seem to corroborate other fisheries indicators regarding the recovery of the Eastern Atlantic and Mediterranean Sea bluefin tuna stock.

RÉSUMÉ

Le présent document met à jour les informations présentées antérieurement sur les prises de thon rouge provenant d'une pêcherie de madrague thonière opérant au large de la côte méridionale de UE-Portugal (Algarve). On a analysé les tendances intra et interannuelles des prises. Depuis 2012, le quota portugais a été atteint alors que le nombre de jours nécessaires pour l'atteindre a diminué. La taille moyenne des poissons a considérablement augmenté et la proportion de gros mâles capturés s'est progressivement accrue. La tendance de la CPUE nominale calculée pour une seule madrague montre une période relativement faible et plane entre 1998 et 2008, suivie d'une forte augmentation au cours des dernières années. Une standardisation préliminaire de la CPUE a été réalisée avec un GLM Tweedie utilisant les effets (saisonniers) d'année et de mois. La tendance de la CPUE standardisée suivait en général la tendance de la CPUE nominale, avec des valeurs relativement faibles et une période plane jusqu'en 2008, suivie d'une forte augmentation et de valeurs beaucoup plus élevées au cours des dernières années. Ces résultats semblent corroborer d'autres indicateurs des pêcheries en ce qui concerne le rétablissement du stock de thon rouge l'Atlantique Est et de la Méditerranée.

RESUMEN

En este documento se actualiza la información, presentada previamente, sobre capturas de atún rojo de una pesquería de almadraba de atún que opera en la costa meridional de UE-Portugal (Algarve). Se analizaron las tendencias de capturas intra-anuales e interanuales. Desde 2012 se ha alcanzado la cuota portuguesa mientras que ha disminuido el número de días requeridos para alcanzar la cuota. La talla media de los peces se ha incrementado significativamente con una mayor proporción progresiva de machos grandes en las capturas. La tendencia de la CPUE nominal calculada para una sola almadraba se muestra relativamente baja y plana entre 1998 y 2008, a lo que siguió un aumento marcado en los últimos años. Se realizó una estandarización preliminar de la CPUE con un GLM Tweedie con efectos año y mes (temporada). La CPUE estandarizada siguió en general las tendencias de la CPUE nominal, con valores relativamente bajos y un período plano hasta 2008, seguido por un aumento

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marcado y valores mucho más altos en los últimos años. Estos resultados parecen corroborar otros indicadores de pesquerías en lo que concierne a la recuperación del stock de atún rojo Atlántico este y Mediterráneo.

KEYWORDS

Bluefin tuna, Algarve (Portugal) tuna trap, catch-at-size, sex-ratios, CPUE standardization

1. Introduction

Tuna traps result from the evolution of a primitive fishing system using passive and plug nets placed in the migratory path of the target species. In the Algarve (southern Portugal), the tuna fishery dates back to the 14th century, becoming more complex through the centuries. In 1903, 19 traps were set in Portuguese waters, of which, only 6 remained in 1927 and none in 1972. The collapse of this fishery in the Algarve was believed to be caused mainly by the free increase of the fishing effort in the Atlantic Ocean and Mediterranean Sea over the tuna species and the consequent depletion of their stocks. Large boats with freezing capacity allied to an intense coastal fishery turned the tuna trap fishery economically unsustainable for the Portuguese fishermen (Costa, 2000). Until 2011 there was only one operational tuna trap in the Algarve (owned by Tunipex), set off Fuzeta since 1995. Since 2012, two additional tuna traps (owned by Real Atunara) were set, although only one was operational in 2012 and 2015 (off Tavira, Barril) and in 2013 (off Faro, Santa Maria), respectively (Figure 1). Like traditional tuna traps, these are composed by a complex net system that leads the individuals through a maze, so they may be trapped and captured (Leite *et al*., 1986).

Since 1998, restrictions in the fishing effort in the East Atlantic Ocean and Mediterranean have been applied to the bluefin tuna (BFT), with consecutively less fishing effort (measured in months of fishing per year) taking place. Additionally, changes in the Minimum Landing Sizes (MLS, measured in kg per caught fish) have been consecutively applied. Starting in 1998 and until 2002, a total 11 months per year were allowed for purse-seiners to fish, with the only no fishing period taking place between the 16th July and the 15th August. For that same period, no restrictions in the fishing period existed for longliners and bait-boats. Starting in 2003, longliners stopped being allowed to fish during June and July (ICCAT Rec. 02-08). Starting in 2007, purse-seiners could only fish for 6 months of the year (not allowed to fish between July and December), longliners could only fish for 5 months per year (could not fish between June and December) and bait-boats could only fish for 6 months per year (could not fish between 15 November and 15 May) (ICCAT Rec. 06-05). From 2009, purse-seiners were only allowed to fish 2 months per year (not allowed to fish between the 15th June and 15th April), longliners were only allowed to fish 5 months per year (not allowed between June and December) and bait-boats only fished 4 months per year (not allowed between the 15th October and 15th June). Since 2009 and for that same period (15th October to 15th June), pelagic trawlers and recreational fishers were also not allowed to fish. Finally, and starting in 2010, the no fishing period for longliners and bait-boats was maintained, with purse-seiners being only allowed to fish for one month of the year. Additionally, restrictions in the minimum landing sizes (MLS) have also been applied over the years. Between 1998 and 2003 the MLS was 6.4 kg, but since 2007 this value was increased to 30 kg or 115cm FL for most Eastern Atlantic and Mediterranean fisheries. All these management measures are now compiled in ICCAT Rec. 14-04.

Given the importance of the bluefin tuna as a marine resource (Fromentin and Powers, 2005), the captures in the Algarve tuna traps have been recorded since 1998. Between 2010 and 2016, five papers were presented to the SCRS describing the catches of the oldest of these tuna traps in terms of number, weight and size between 1998 and 2016 (Santos and Coelho, 2011; Santos *et al*., 2011, 2014, 2016; Lino, Rosa and Coelho, 2016). The main objective of the current working document is to update the latter papers with more recent data collected during the 2011 to 2016 fishing seasons. Furthermore, size distributions by sex are now presented, since an effort to register the fish sex was carried out in 2012-2016. Finally, following BFT WG recommendations, a preliminary standardized CPUE series was estimated.

2. Materials and methods

2.1. Data collection

Catch and catch-at-size data was regularly collected by IPMA (*Instituto Português do Mar e da Atmosfera*) technicians throughout the fishing season within the scope of the National and European fisheries data collection framework. All BFT size data in this paper refers to fork length (FL) in cm, while biomass refers to live weight (kg).

2.2. Data analysis

Data, including nominal catches and individual specimen sizes, was available and analysed for the period between 1998 and 2016.

The catches of the Santa Maria and Barril traps were not considered for the current study, as these traps have only operated alternatively in the last 6 years, and only operated on the same year in 2014 and 2016. The Santa Maria trap is located on the western side of the south cost (off Santa Maria Cape, see **Figure 1**), and in the past its activity corresponded mostly to early catches in the season (during the fish migration into the Mediterranean Sea). Whereas the Fuzeta and Barril traps are located to the east part of the coast and catch mostly tuna that has left the Mediterranean (during the migration into the Atlantic after spawning).

The ranges of the sizes of BFT caught per year were explored with boxplots and plots of means with the respective standard errors. For the most recent years (2012 to 2016) partial data was available for the separate sexes, while in the earlier years sex-specific data is not available. However, the sex specific data was not available for all captured specimens. Specifically, it was available for 2,362 specimens which represents 25% of the sampled specimens in that period. Size data was tested for normality with Kolmogorov-Smirnov tests (with Lilliefors correction) and for homogeneity of variances with Levene tests. Catch sizes were then compared between years with non-parametric Kruskal-Wallis tests, given that the data was not normally distributed and the variances were heterogeneous. The sex-ratios were calculated and compared between years and the size classes (5 cm FL) with contingency tables and Pearson's Chi-squared tests.

Data used to calculate and standardize the CPUE was available between 1998 and 2016 for the Fuzeta tuna trap (operated by company Tunipex). The CPUE (response variable) was measured in N BFT per fishing day (N/day).

The standardized CPUE series was estimated with Generalized Linear Models (GLMs). Only year and seasonal (month) explanatory variables were possible to include in the models, as the data comes from only one fixed trap so there are no spatial effects/variability to consider. The variable tested and used were:

- Year: categorical variable, analyzed between 1998 and 2016;
- Month: categorical variable, 1 level for each month. The initial (2-4) and final months (10-11) were grouped as there was less data on those.

The model structures and distributions tested included the following:
- GLM Poisson
- GLM Negative Binomial
- GLM Tweedie
- Zero-Inflated Negative Binomial (negative binomial for the count process and binomial for the excess zeros): only tested preliminary model runs.

The significance of the explanatory variables (year and month) was assessed with likelihood ratio tests comparing each univariate model to the null model, and by analyzing the deviance explained by each covariate. Goodness-of-fit and model comparison was carried out with the Akaike Information Criteria (AIC). Models we also assessed with residual analysis. Possible interactions between year and month (tested with GLMM - Generalized Linear Mixed Models) were not used due to convergence problems in the models, likely because of lack of sufficient data in the various interaction levels of the covariates.

The final estimated indexes of abundance (standardized CPUEs) were calculated by least square means (LSMeans or Marginal Means). For comparison purposes between models, the standardized CPUEs were scaled by their respective means.

Data analysis for this paper was carried out in the R language for statistical computing 3.3.2 (R Core Team, 2016), with the plots designed using library ggplot2 (Wickham, 2009) and analysis using libraries car (Fox and Weisberg, 2011), dunn.test (Dinno, 2017), FSA (Ogle, 2016) gmodels (Warnes *et al*, 2015), nortest (Gross and Ligges, 2015), tweedie (Dunn, 2013) and lsmeans (Lenth, 2014).

3. Results

3.1. BFT catches and periods of operation of the tuna traps

In the early years of operation and until 2009 the BFT quotas were not reached, with the trap catching less than 25% of the BFT allowed quota (**Figure 2**). This pattern changed after 2010, when much more BFT were captured and the quotas were reached. As a consequence, the number of trap operation days targeting BFT (used as the measure of effort) showed a decreasing trend along the years, with less days needed to reach the BFT quota. Since 2011 the fishing season has been less than 2.5 month, usually starting in late April and closing in early/mid-July (**Figure 2**). In 2016 the effective tuna fishing period started earlier with a single fish being registered in late April.

3.2. Size structure of the catches

Between 1998 and 2016 a total 10,336 BFT were sampled for size. The sizes ranges of the BFT caught in the tuna traps showed some variation within the period. A general decreasing trend in the mean size was noted until 2007, followed by an increase thereafter, which was particularly noted since 2011 (**Figure 3**). The length frequency distributions shown in **Figure 4** denoted the increase on the modal classes over several periods (1999-2004, 2005-2010 and 2011-2016), which allow following the influence of some particular cohorts. Significant differences between years were detected (Kruskal-Wallis: $Chi^2 = 1505.8$; df = 17; p-value < 0.001). This test was used instead of a parametric ANOVA due to the lack of normality in the data (Lilliefors test: D = 0.028, p-value < 0.001) and heterogeneity of variances (Levene: F = 36.78; df = 17; p-value < 0.001).

For the sex-specific size distributions, and even though data is only partially available for the most recent years, a slight increase in the mean sizes was observed for both males and females between 2012 and 2013. In 2014 a slight decrease was noted for females, while an increase was recorded for males but both increased since 2014 (**Figure 5**). These differences were statistically significant (Kruskal-Wallis: $Chi^2 = 242.45$; df = 4; p-value < 0.001 for females and Kruskal-Wallis: $Chi^2 = 199.56$; df = 4; p-value < 0.001 for males). A Dunn *post hoc* test showed that the differences for females were significant between all pairs of data except for 2012-2014 and 2013-2015 (Dunn: $z = 0.74$; p-value > 0.05 and $z = 0.16$; p-value > 0.05). For males the differences in mean sizes were statistically different between all pairs of values except between 2013-2014 and 2014-2015 (Dunn: $z = -0.55$; p-value > 0.05 and $z = -1.70$; p-value > 0.05).

3.3. Sex-Ratios

The sex-specific data showed that more females than males are usually captured in the Algarve tuna traps, with an overall sex-ratio of 58.3% females and 41.7% of males. These differences in the sex ratios were similar for the five years (**Figure 6**), and no significant differences were detected when comparing the sex-ratios between the years ($Chi^2 = 8.53$; df = 4, p-value = 0.074). With regards to the sex-ratios in the catch-at-sizes, it was possible to observe a trend with the smaller size classes having more females and the larger size classes having more males, with those differences statistically significant ($Chi^2 = 178.66$; df = 34, p-value < 0.001). In fact, males' dominance was evident at sizes greater than 225 cm, whereas females were more abundant than males in most size classes below 225 cm. (**Figure 7**).

3.4. Standardized CPUE

There was a large number of fishing days with BFT catches = 0, specifically 74.0% of the days, with yearly variations between 31.3% and 96.1% (**Figure 8**). The nominal CPUE time series is shown in **Figure 9**. In general the CPUEs were low until 2009, and since then have been increasing for the more recent years.

The nominal BFT CPUE data is over-dispersed (dispersion parameter from Poisson model = 31.5). The distribution is highly skewed to the right due to the presence of both the large mass of zeros and some very high values (**Figure 10**). Even the log-transformed data (positives only) shows asymmetry with a tail to the right (**Figure 10**).

In terms of model fit the following is noted:

- GLM Poisson: data is over-dispersed so the model fit is poor.
- GLM Negative Binomial: model fit seems in general OK but there are problems in the residuals.
- GLM tweedie: model fit and residuals seem in general OK.
- Zero-Inflated Negative Binomial: only preliminary model runs and results (model fit seems OK, but there is no residual analysis at this stage - to be further tested in the future).

The residuals of the best fitted model (tweedie) are shown in **Figure 11**. On this model both the year and month effects were significant (**Table 1**). The factor that contributed most for the deviance was the year followed by the month (**Table 1**).

The final standardized BFT series from this model is shown in **Figure 12**.

4. Discussion

Over the last 15 years, there have been significant changes in the fishing restrictions for bluefin tuna in the Eastern Atlantic Ocean and the Mediterranean Sea. Those restrictions have been implemented both in terms of the allowable number of fishing months for each fishing gear per year, as well as in terms of the minimum landing sizes (in this specific case measured in terms of weight) of caught specimens. A paper by Cort and Martínez (2010) estimated that at least 840,000 juvenile bluefin tuna per year have been spared from the fisheries in the western Mediterranean since the implementation of restrictions to the capture of fish with less than 30kg (ages 1-4) in 2007. The latter authors further mentioned that some of the cohorts potentially protected (2003, 2004 and 2005) had already joined the spawning population so the benefits of those measures are probably already taking place. The results of the present study, seems to evidence that as the fishing effort in the Mediterranean decreased, the catch in the Algarve tuna trap increased. Independently of the monthly (or season, late spawners *versus* post-spawning) contribution to the overall estimated trap potential catches, since quota first reached (in 2012) there was a decreasing trend on the duration of the fishing season. However since 2014 the number of fishing days to reach quota have been slowly increasing not only because the quota has been increasing but also because (particularly in 2016) the first tunas were caught earlier than in the previous two years.

Although Santos and Coelho (2011) mentioned that the high catches of bluefin tuna in the Algarve trap during 2010 seemed an extreme outlier, it is important to put recent potential catch values into perspective in historical terms. As an example, in 1960 the Barril tuna trap (off the Algarve coast, southern coast) caught a total of 1,848 bluefin tuna specimens, most of which weighing more than 50 kg (Costa, 2000). Further, the latter author mentioned that those values for 1960 were on the lower side of the catch range, given that average numbers in the order of the 4,000 tunas per year were common during the 1950's in that tuna trap. Santos and Coelho (2011) and Santos *et al.* (2014) forwarded the hypothesis that the level of catches in the Algarve tuna trap fishery in the early 2010's, could already be reflecting the substantial reductions in the fishing season (and effort) that took place in the Mediterranean since 2007. Considering that, according to Cort and Martínez (2010), some of the cohorts potentially protected (2003, 2004 and 2005) had already joined the spawning population and the size range of the Algarve trap catches, it seem the case that the recent catches consists mostly of specimens from those cohorts. In fact, this conclusion is supported by the increasing trend on the size structure of the BFT catches observed over the last five years, which followed a decreasing trend recorded until 2007.

The standardized CPUE series shows low values until 2009 and have been increasing since then. It should also be noted that since 2012 the Portuguese quota has been reached. This means that there is no information on catches per day after the end of quota warning is issued.

These models are the first trials for standardizing the BFT CPUEs from the Portuguese tuna trap and should be regarded as preliminary. It should also be emphasized that the data used is from only one tuna trap (and the other 2 traps have only operated for very few years). As such, the models are only using year and seasonal (month) effects, but not spatial effect (as the tuna trap is set/fixed so there is no spatial variability). Future work on these models will be to continue to explore Zero-Inflated Models (especially Zero Inflated Negative Binomial, due to zero inflation and over-dispersion of the data) and explore hurdle models (similar to the Delta method approach, but using a discrete count model for the positives, instead of the continuous lognormal usually used in the Delta method).

As a conclusion, this study provides further evidence of the recent signs of recovery of the eastern Atlantic and Mediterranean bluefin tuna. Such recovery seems to be due to strong recruitment between 2003 and 2005 and, at least, partially to the fishing management measures in place for the Mediterranean Sea. However, the results presented in the present study should still be considered with some caution, as the time series analysed is still relatively short (1998-2016). However, the observations on the need for shorter fishing periods to reach the same catch level seems to evidence that bluefin tuna catches are returning to the historical catch rates observed during the 1950's off the Algarve coast. Still, as more data from the tuna trap fishery off the Algarve becomes available over the next years, the hypothesis now raised will be revisited and further analysed as will continue the work on the CPUE standardization.

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Table 1. Deviance table of the parameters used for the BFT CPUE standardization models for Portuguese tuna trap off the Algarve, Portugal, using a Tweedie GLM with link=log. For each parameter it is indicated the sum of squares (SS), the degrees of freedom (Df), the F-test statistic and the significance (p-value).

```
Analysis of Deviance Table (Type II tests)

Response: BFT
             SS   Df      F    Pr(>F)    
Year       4358   18 15.596 < 2.2e-16 ***
Month2     1705    7 15.688 < 2.2e-16 ***
Residuals 32845 2116                     
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

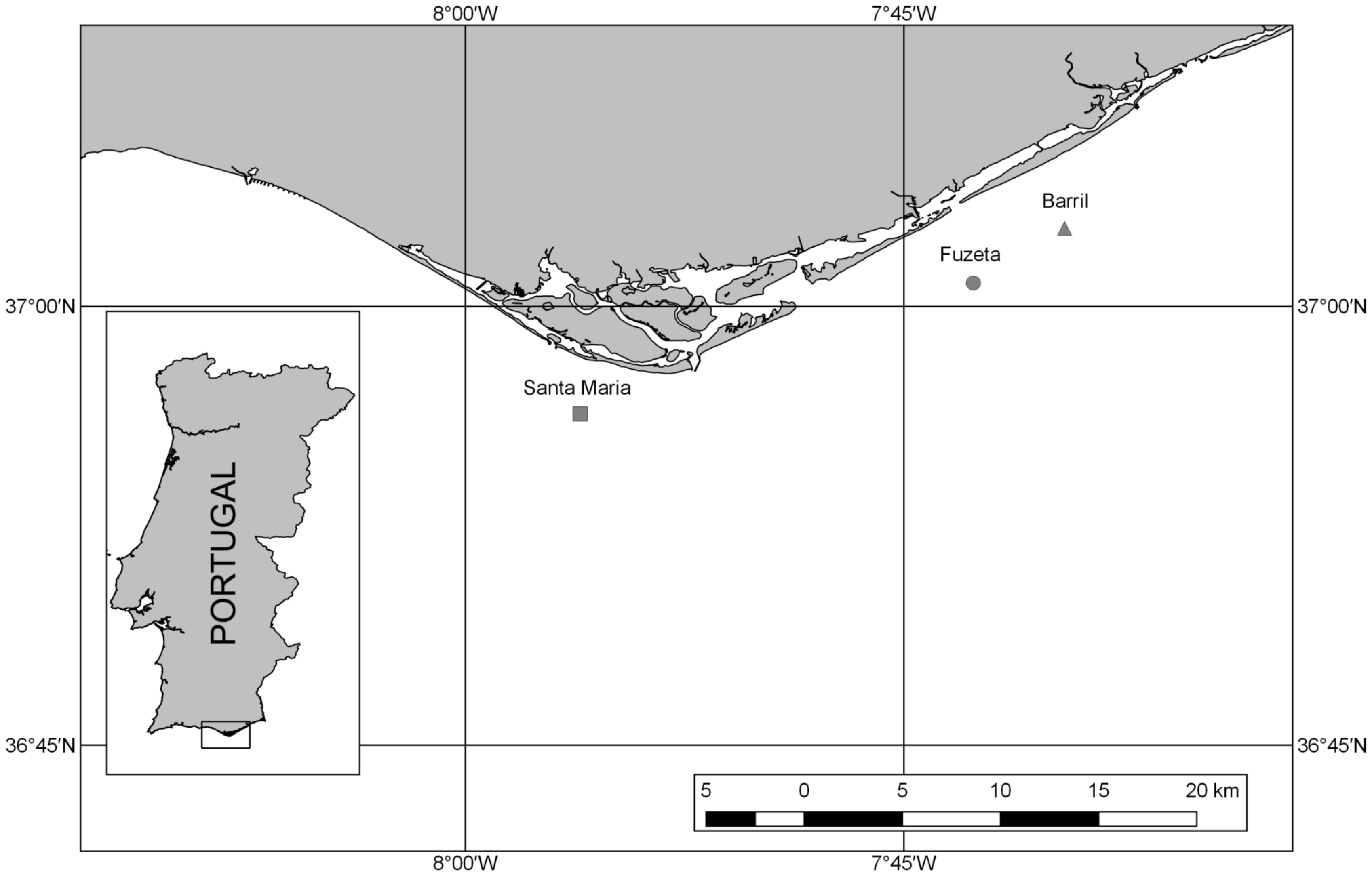

Figure 1. Location of the Algarve tuna traps.

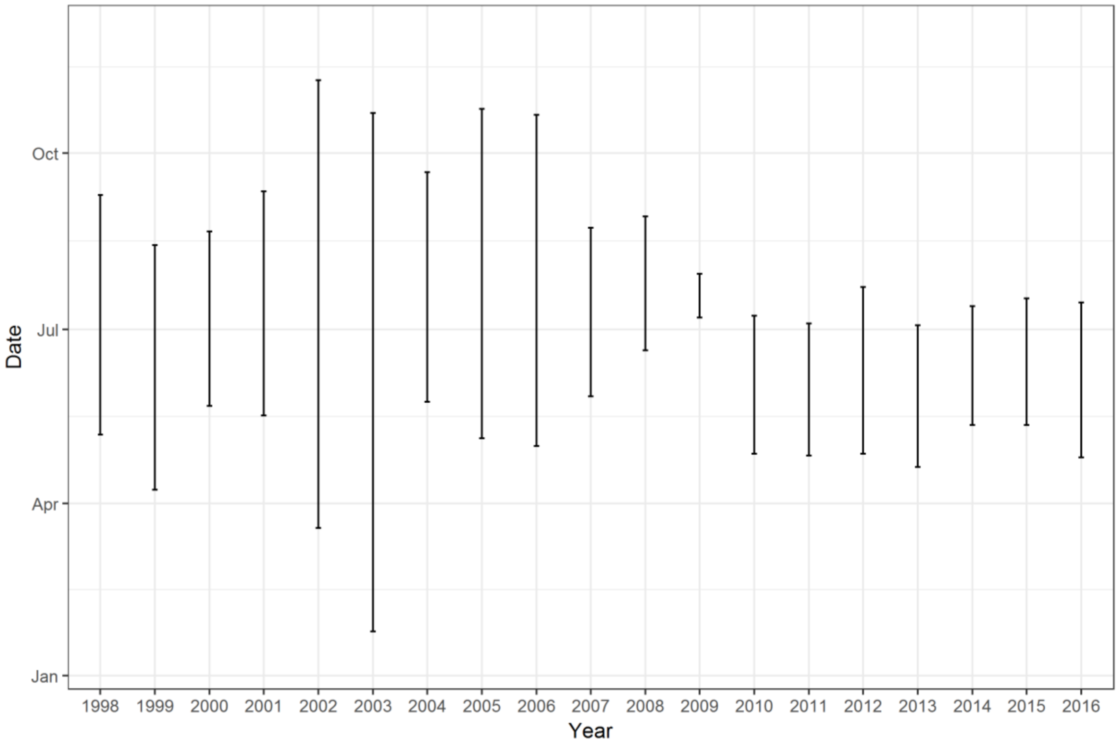

Figure 2. Annual period of activity of the tuna traps targeting bluefin tuna along the time series. Strong recruitment of mussels on the trap nets in 2009 restricted the fishing season to a single month.

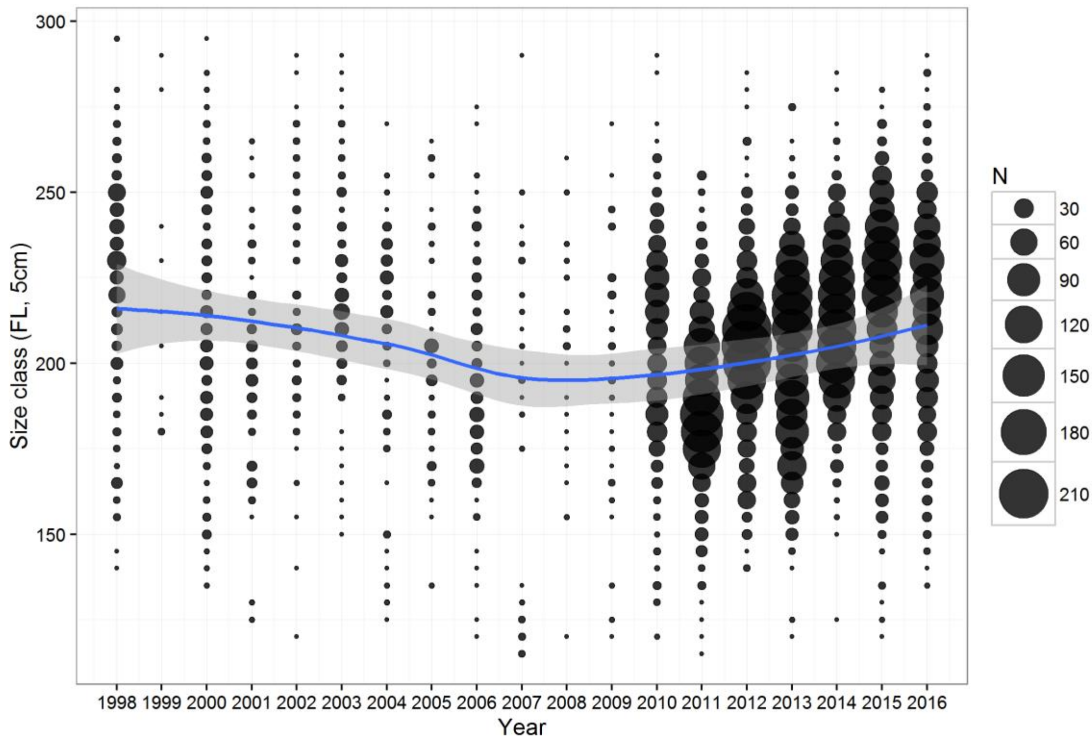

Figure 3. Annual size distribution of the captured bluefin tuna (by 5 cm FL size classes) along the study period (1998 to 2016), with a Loess (locally weighted scatterplot smoothing) regression line and the respective 95% confidence intervals (grey shadow. Fish less than 115cm were not included for this analysis.

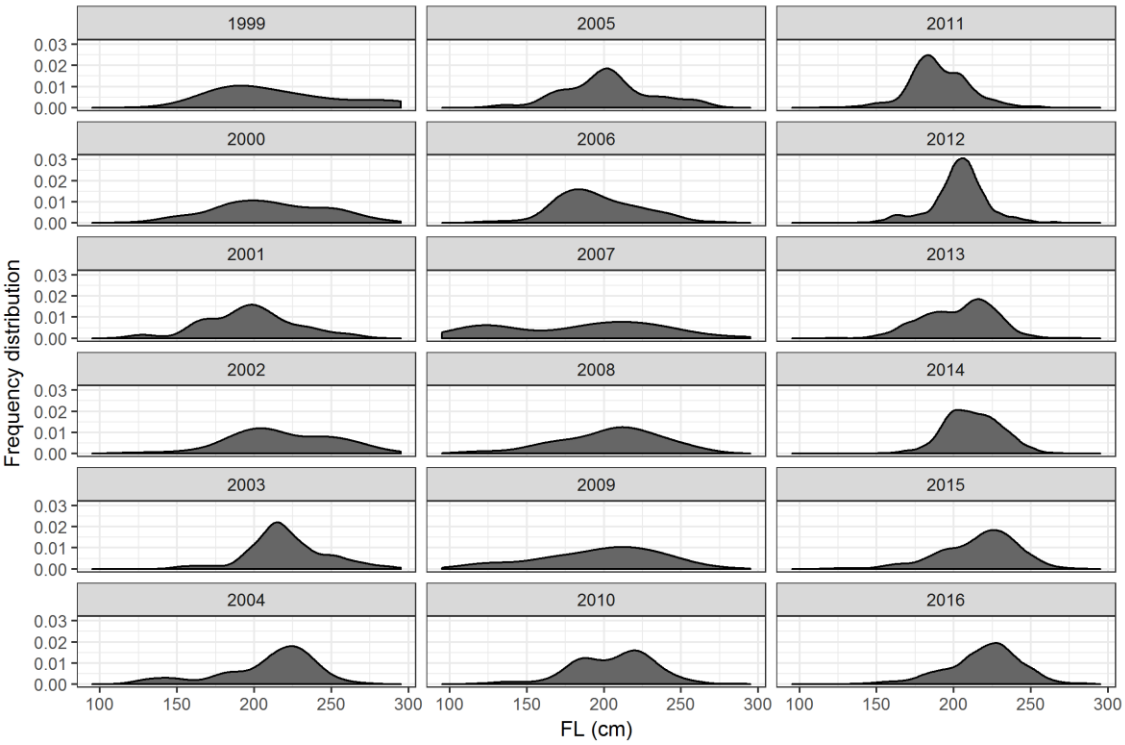

Figure 4. Yearly size frequency distribution of bluefin tuna (by 5 cm FL size classes) caught in the tuna traps off the Algarve between 1999 and 2016. Fish less than 115cm were not included for this analysis.

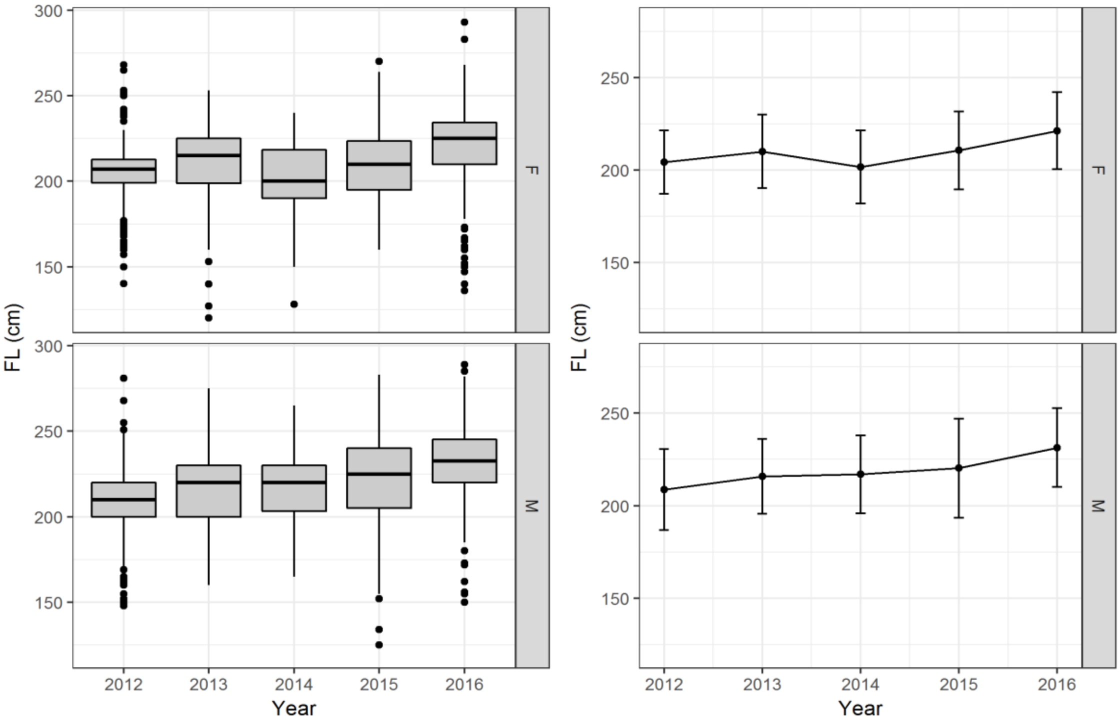

Figure 5. Sex-specific yearly catch-at-size of BFT caught in the tuna traps off the Algarve between 2012 and 2016, represented as boxplots with the median, inter-quartile range and range (left) and as the yearly averages with ± standard deviation (right). Fish less than 115cm were not considered for this analysis. The sex specific sample (2,362 specimens) represents 25% of the sampled fish during that period.

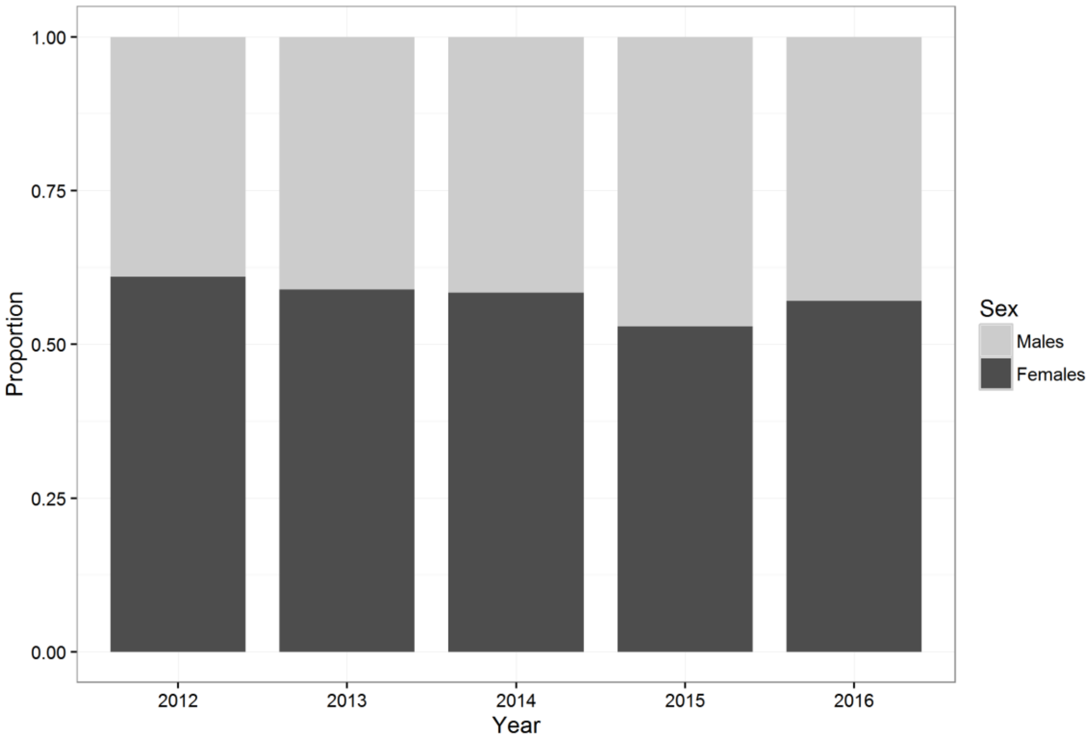

Figure 6. Yearly sex-ratios of BFT captured in the Algarve tuna traps in 2012 and 2015. The sex specific sample (2,362 specimens) represents 25% of the sampled fish during that period.

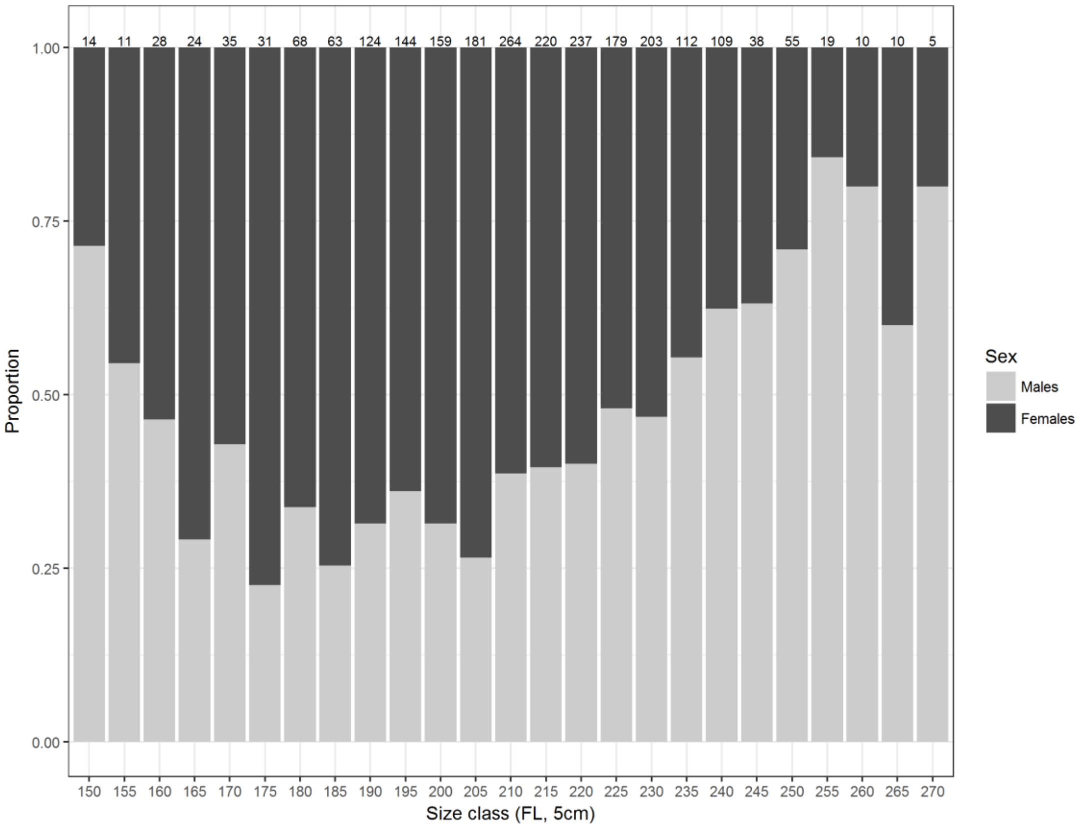

Figure 7. Sex-ratios by size classes (5cm FL) of the BFT captured in the Algarve tuna traps between 2012 and 2016. The sex specific sample (2,362 specimens) represents 25% of the sampled fish during that period. The figures at the top represent the number of specimens sampled per 5 cm FL size classes. Classes with n<5 are not shown.

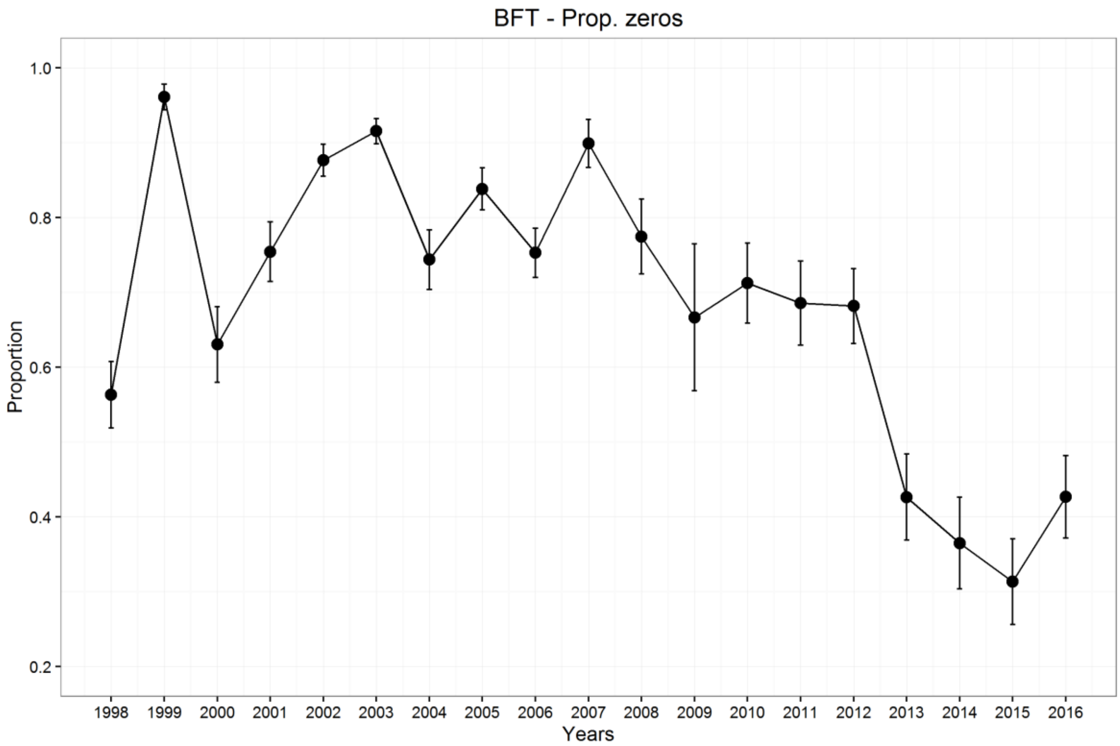

Figure 8. Proportion of days (effort) with 0 BFT catches during the tuna trap operation season, between 1998 and 2016. The error bars refer to the standard errors.

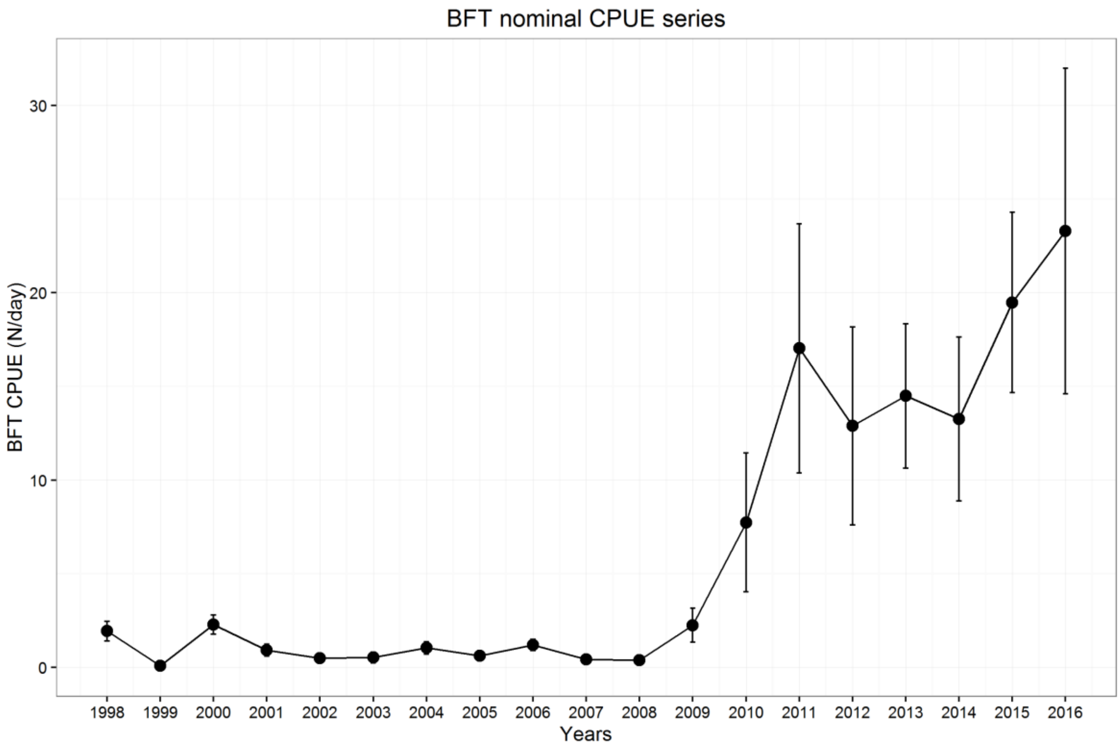

Figure 9. Nominal CPUE series (N/day) for BFT caught in the tuna trap off the Algarve, Portugal, between 1998 and 2016. The error bars refer to the standard errors.

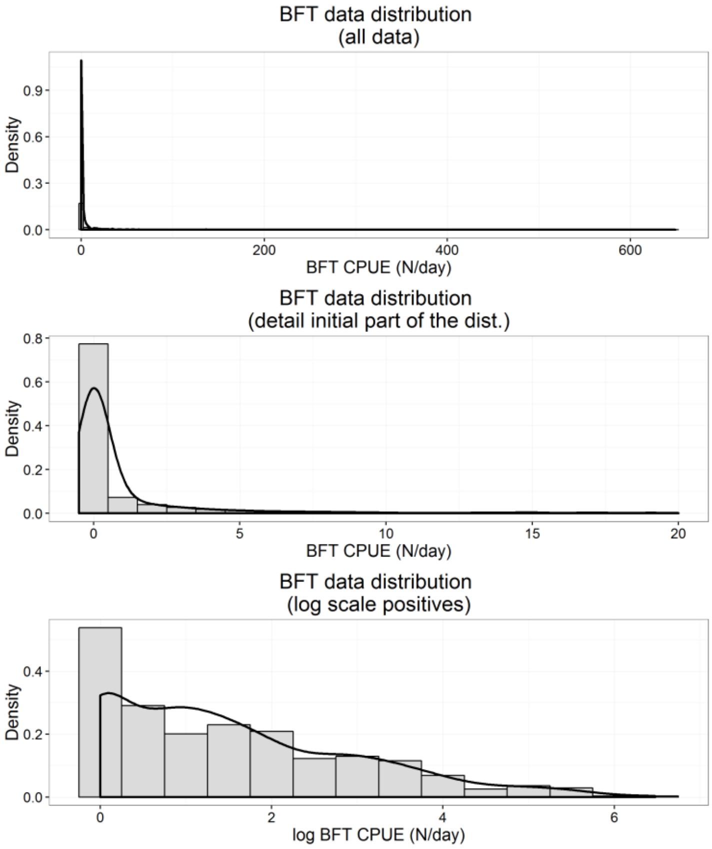

Figure 10. Distribution of the nominal BFT CPUE (N/day) captured by the Portuguese tuna trap off the Algarve, Portugal. The plot on the top represents all data available, the plot in the middle represents the detail of the initial part of the distribution and the plot in the bottom represents the data in log-scale (positives only).

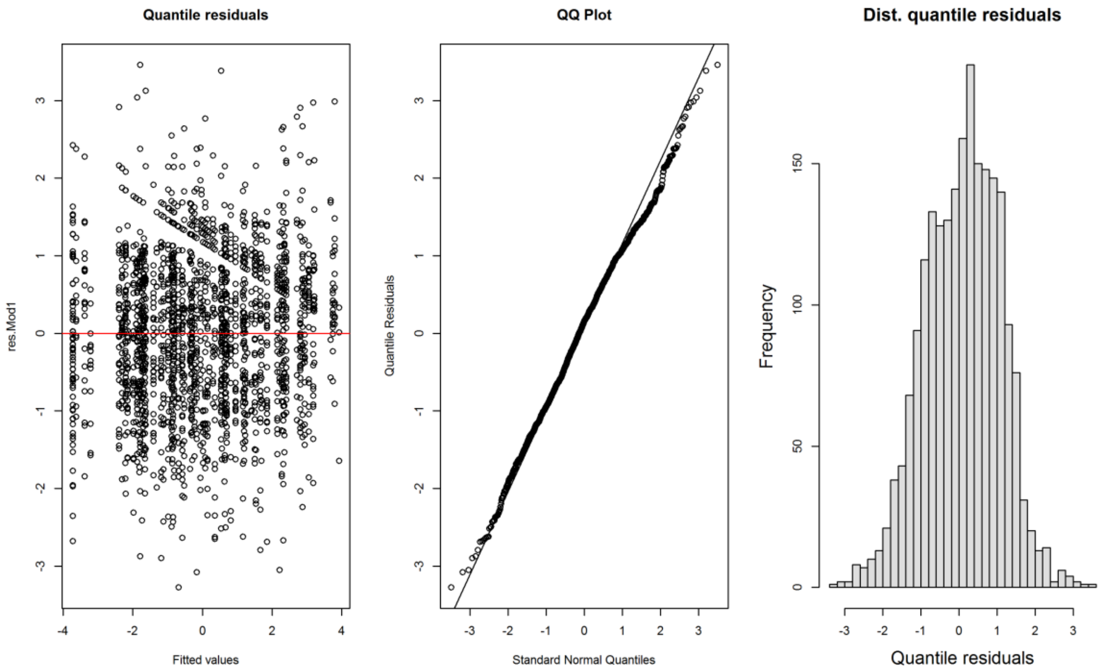

Figure 11. Residual analysis for the Tweedie GLM for the Atlantic BFT standardization in the tuna trap off the Algarve, Portugal. The plots represented the residuals along the fitted values (left), the QQPlot (middle) and the histogram of the distribution of the residuals (right).

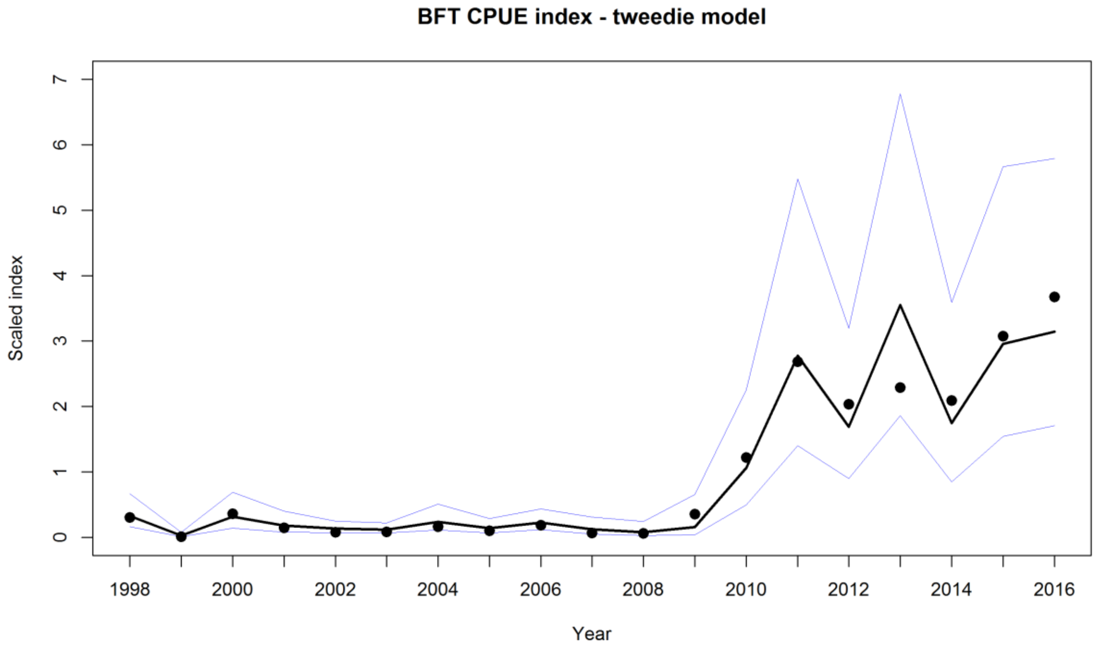

Figure 12. Standardized CPUE series for BFT captured by the Portuguese tuna trap off the Algarve, Portugal using a Tweedie GLM (black line). The light blue lines are the 95% confidence intervals of the standardized series and the nominal series is represented in the black dots. For comparison purposes both the standardized and nominal CPUEs were scaled by their respective means.