NEW OBSERVATIONS ON THE BLUEFIN TUNA TRAP FISHERY OFF SOUTHERN PORTUGAL (NE ATLANTIC) BETWEEN 1998-2014: TRENDS ON POTENTIAL CATCHES, CATCH-AT-SIZE AND SEX RATIOS

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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 and relationships between the potential catches and ICCAT management regulations for the Mediterranean Sea explored. The catch rates of bluefin tuna in the tuna trap off the Algarve remained relatively low between 1998 and 2008, but were followed by increasingly high catches thereafter, with an observed peak during the 2011 season. Significant negative correlations were observed between the catches and the number of allowable fishing months for purse-seines, longlines and bait boats in the Mediterranean Sea, meaning that the catch increased as the number of allowable fishing months for those fishing gears decreased. On the other hand, a positive relationship was observed between the catches and the minimum landing size (MLS), meaning that the catch rates in the tuna trap increased as the MLS for bluefin tuna also increased. These results seem to corroborate other fisheries indicators regarding the recovery of the Eastern Atlantic and Mediterranean Sea 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). Ce document analysait les tendances des prises intra et interannuelles et étudiait les relations entre les prises potentielles et les réglementations en matière de gestion de l'ICCAT en Méditerranée. Les taux de capture du thon rouge dans la madrague thonière au large de l'Algarve sont restés relativement faibles entre 1998 et 2008, mais ils ont été suivis par des prises de plus en plus fortes par la suite, avec un pic observé au cours de la saison 2011. De considérables corrélations négatives ont été observées entre la prise et le nombre de mois de pêche admissibles pour les senneurs, les palangriers et les canneurs dans la mer Méditerranée, ce qui signifie que la prise augmentait au fur et à mesure que diminuait le nombre de mois de pêche admissibles pour ces engins de pêche. En revanche, une relation positive a été observée entre les prises et la taille minimum au débarquement (MLS), ce qui signifie que les taux de capture dans les madragues thonières augmentaient au fur et à mesure qu'augmentait aussi la MLS du thon rouge. Ces résultats semblent corroborer d'autres indicateurs des pêcheries au sujet du rétablissement du stock de l'Atlantique Est et de la Méditerranée.

RESUMEN

En este documento se actualiza la información 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 intra e interanuales y se exploraron las relaciones entre las capturas potenciales y las reglamentaciones de ordenación de ICCAT para el Mediterráneo. Las tasas de captura de atún rojo en la almadraba del Algarve permanecieron relativamente bajas entre 1998 y 2008, pero posteriormente fueron aumentando cada vez más, con un pico en la temporada de 2011. Se observaron significativas correlaciones negativas entre las capturas y el número de meses que pueden pescar los cerqueros, los palangreros y los cañeros en el Mediterráneo, lo que significa que la captura aumentaba a medida que el número de meses de pesca permitida de estos artes disminuía. Por otra parte, se observó una relación positiva entre las capturas y la

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talla mínima de desembarque (MLS), lo que significa que las tasas de captura de la almadraba aumentaron a medida que la MLS para el atún rojo también aumentaba. Estos resultados parecen corroborar otros indicadores pesqueros sobre la recuperación del stock del Atlántico este y Mediterráneo.

KEYWORDS

Bluefin tuna, Algarve (Portugal) tuna trap catch,
Catch-at-size, Sex-ratios, Fisheries management in the Mediterranean

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 mainly caused by the free increase of the fishing effort in the Atlantic Ocean 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 Atunara) were set, although only one was operational in 2012 (off Tavira, Barril) and 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 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 & Powers, 2005), the captures in the Algarve tuna traps have been recorded since 1998. Between 2010 and 2014, three 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 2010 (Santos & Coelho, 2011; SCRS/2011/157 and SCRS/2014/046). The main objective of the current working document is to update the latter papers with more recent data collected during the 2011 to 2014 fishing seasons. Furthermore, size distributions by sex are now presented, since an effort to register the fish sex was carried out in 2012-2014.

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 was analysed for the period between 1998 and 2014. Specific data on numbers (N) and biomass (kg) caught per month in each year were available for the entire period. Data on the individual specimen sizes was available and analysed between 1998 and July 2014. The catch was further analysed in terms of catches per month along the years.

It is worth noting that for 2010 to 2014 the figures presented herein do not represent effective catch, as since the day when the available quota was reached a substantial number of specimens were released after entering the trap. The released fish were counted and a visual estimation of their average weight was recorded. Thus, these figures should be interpreted as estimates of potential BFT catches (catch + estimated releases) by the two eastern tuna traps (Fuzeta and Barril) as by the 15th July of each year. Moreover, the catches of the Santa Maria trap were not considered for the current study, as this trap has only operated for 2 years, with some limitations in the course of the first year (2013). The latter trap is located on the western side of the south cost (off Santa Maria Cape), 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.

The ranges of the sizes of BFT caught per year and per month were explored with boxplots and plots of means with the respective standard errors. For the most recent years (2012 to 2014) 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 1531 specimens which represents 27.9% of the traps' effective catch 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 and between months 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.

The relationships between the fishing restrictions (particularly in the Mediterranean Sea) and the catch of BFT in the tuna trap off the Algarve (in weight) were analysed by calculating correlation coefficients with their respective p-values. These fishing restrictions were measured as: 1) the number of allowable fishing months per year for each of the fishing gears (purse-seine, longline and bait-boats), and 2) the minimum BFT landing size (in kg). The correlations used were the Pearson product-moment correlation (that assumes a linear relationship between the variables), and the non-parametric Spearman's rank and Kendall's rank (that rank the values and do not assume linear relationships between the variables). As in recent years the nets that guide the fish into the trap were removed when the quota was reached, avoiding additional labour to release the fish, we limited the analysis to those potential catches until 15th July. This date corresponds roughly to the date of the net removal in recent years.

Data analysis for this paper was carried out in the R language for statistical computing 3.0.1 (R Core Team, 2013), with the plots designed using library ggplot2 (Wickham, 2009).

3. Results

3.1 Total yearly potential catch in weight

Between 1998 and 2014, the total amount of bluefin tuna entering the tuna trap (potential catch) ranged from an annual minimum of 8,868 kg (corresponding to 67 individuals) in 1999, to an estimated maximum of 835,742 kg (corresponding to 5498 specimens) in 2011 (**Figure 2**). Catches remained relatively low until 2009 (25 MT/year on average), but then increased substantially in 2010 (aprox. 290 MT) and even more during 2011 (over 835 MT), followed by a sharp decrease to the level of 2010 and a new strong increase in 2014 (**Figure 2**). Moreover, in recent years large schools were persistently observed by fishermen off the south Algarve coast throughout July and August. During 2012 and 2013, these schools were mostly observed further off-shore, which associated to lower SST maybe the cause of the decrease of the potential catches during those years when compared to the 2010 and 2014 figures.

3.2 Monthly distribution of the catches

A pattern was observed in the monthly catches (in weight) of BFT along the fishing season (April to October), with major catches occurring during the warmer months, from June to August (over 85%), with the highest monthly catches taking always place during July, when on average over 58% of the fish were retained in the trap. Moreover, in 2010 and 2014, the potential catch in July reached 90% (**Figure 3**). Traditionally, this peak on the local catches corresponds to fish with a poor condition, which were on their way back to the Atlantic Ocean after the spawning season in the Mediterranean Sea. However, it is worth noting that in recent years, namely since 2011, but specifically in 2013, much higher catches were observed earlier in the season, namely in May, corresponding of catches of both late spawners and poor condition fish.

3.3 BFT catches and periods of operation of the tuna traps

In the early years of operation and until 2009 the BFT quotas were never reached, with the trap catching less than 25% of the BFT allowed quota (**Figure 4**). This pattern changed specifically after 2010, when much more BFT were captured and the quotas were reached. As a consequence, the number of trap operation days for targeting BFT showed a decreasing trend along the years, with less days needed to reach the BFT quota. Since 2011 the fishing season is restricted to less than 2.5 month, starting in late April and closing in early/mid-July (**Figure 4**).

3.4 Size structure of the catches

Between 1998 and 2014 a total 7,355 BFT were sampled for size. The sizes ranges of the BFT caught in the tuna traps showed some variation between 1998 and 2014. A general decreasing trend in the mean size was noted until 2007, followed by an increase thereafter, which was particularly noted since 2011 (**Figure 5**). The length frequency distributions shown in **Figure 6** denoted the increase on the modal classes over several periods (1999-2004, 2006-2004 and 2010-2014), allow following the influence of some particular cohorts. Significant differences between years were detected (Kruskal-Wallis: $Chi^2 = 939.9$; df = 16; 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 = 0.032, p-value < 0.001) and heterogeneity of variances (Levene: F = 40.6; df = 16; 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 (**Figure 7**). These differences were statistically significant (Kruskal-Wallis: $Chi^2 = 38.8$; df = 2; p-value < 0.001 for females and Kruskal-Wallis: $Chi^2 = 23.0$; df = 2; p-value < 0.001 for males). A Dunn *post hoc* test showed that the differences for females were significant between 2012-2013 and 2013- 2014 (Dunn: $z = -5.31$; p-value < 0.001 and $z = 4.98$, p-value < 0.001), but not between 2012 and 2014 (Dunn: $z = 1.23$; p-value > 0.05). For males the differences in mean sizes were statistically different between 2012-2013 and 2012-2014 (Dunn: $z = -4.27$; P < 0,001 and $z = -3.60$; p-value < 0.001), while between 2013 and 2014 the differences were not statistically different (Dunn: $z = -0.50$; p-value > 0.05).

A monthly trend on the catch at size was observed during the fishing period, with the largest specimens caught mostly between April and August, while specimens caught at the end of the season (in late October) tended to be smaller (**Figure 8**). The different sizes of BFT caught in the different months were significantly different (Kruskal-Wallis: $Chi^2=331.1$; df = 7; p-value < 0.001).

3.5 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 60.0% females and 40.0% of males. These differences in the sex ratios were similar for the three years (**Figure 9**), and no significant differences were detected when comparing the sex-ratios between the years (Chi-square = 0.809; df = 2, p-value = 0.667). 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-square = 98.14; df = 29, p-value < 0.001). In fact, males' dominance was evident at sizes greater than 225 cm, whereas females were more abundant than males in all size classes below 225 cm (**Figure 10**).

3.6 Correlations between catches and management regulations for the Mediterranean

Significant correlations were established between the BFT catches (between 1998 and 2014) and the fishing effort in the Mediterranean Sea, measured as the number of months with allowable fishing. Those significant correlations were found for purse seines, longlines and bait boats (**Table 1**). Likewise, significant correlations were also established between the trap potential catches of BFT and the MLS (**Table 1**). The results of the correlations were similar considering the Pearson product-moment correlation (that assumes a linear relationship between the variables) and the non-parametric Spearman's rank and Kendall's rank correlations (that rank the variables and do not assume linear relationships).

The correlations between the catch and effort (measured as the number of month of allowed purse seine, longline and bait boats could fish) were negative, meaning that the catch increased as the number of fishing months in the Mediterranean decreased. On the other hand, the correlation between the potential catch and MLS was positive, meaning that the two variables are directly correlated with the catch increasing as the MLS also increases. No significant correlations were found between the catch and the mean SST (**Table 1**).

4. Discussion

In the tuna trap fishery off the Algarve the catches of bluefin tuna remained relatively low until 2009. However, a substantial increase in bluefin tuna entering the trap was recorded during 2010, followed by an even greater increase in 2011. In recent years (2012 to 2014) although the potential catch were not as high as that estimated for 2011, they are still at a very high level when compared to the 1990's and 2000's levels. In recent years there are reports that both the Spanish and Moroccan traps also showed much higher levels on available biomass than during the 2000's (Abid *et al.*, 2014). Moreover, although traditionally the catches of BFT in the Algarve trap fishery (90-95% in number) occur during the warmer months of the year, specifically during July when low conditioned fish exit the Mediterranean Sea (Block *et al.*, 2005; Medina *et al.*, 2011) after the May-June spawning season (Karakulak *et al.*, 2004). However, in recent years the contribution of the spawning season for the Algarve tuna trap catches (fat fish) has increased (representing 6%, 15%, 43% and 97% in 2010, 2011, 2012 and 2013, respectively), but in 2014 it decreased to 11%. Independently of the monthly (or season, late spawners *versus* post-spawning) contribution to the overall estimated trap potential catches, in recent years there has been a decreasing trend on the duration of the fishing season (88, 75, 63 days in 2012, 2013 and 2014, respectively).

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 & 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, namely the negative correlations between the number of allowable fishing months in the Mediterranean Sea and catches of BFT in the tuna trap off the Algarve seems to evidence that as the fishing effort in the Mediterranean decreased, the catch in the Algarve tuna trap increased.

Although Santos & 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. Thus, when compared to the 4,000 specimens per year captured during the 1950's, the mean potential catches of the tuna traps of 2,780 tunas (number of fish ranged from 1,937 to 5,222 in the 2010-2014 period), no longer seem that odd or unusual. Santos & Coelho (2011) and SCRS/2014/046 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. The results of the update figure for 2014 seem to confirm that preliminary hypothesis. In fact, it seems now more evident that the high potential catch rates in recent years were not isolated outliers, but possibly the return of this tuna trap to the historical catch rates of the 1960's and 1950's. Considering that, according to Cort & 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.

Santos & Coelho (2011) and SCRS/2011/157 raised a word of caution as regards the 2010 and 2011 results, because those would not necessarily mean that a causal effect between the variables was taking place (correlation analysis is highly sensitive to outlier values), but after a 5-year period of much higher potential catches than in the previous 12 years period it seems clear that ICCAT management measures are being effective.

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. Specifically, significant negative correlations were observed between the total catch and the number of allowable fishing months with purse-seines, bait-boats and longlines, meaning that the catch increased as the number of allowable fishing months for those fishing gears decreased in 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 (1998-2014). However, the observed increases in potential catch trends and shorter fishing period (to reach the same catch level), should no longer be considered as preliminary 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.

Acknowledgements

Data for this work was collected within the Portuguese National Program of Biological Sampling (PNAB) integrated in the EU Data Collection Framework. Thanks are due to the TUNIPEX, SEAEXPERT staff and IPMA technicians (Tibério Simões, José Luis Sofia, Lina Reis, Sérgio Goes and Ruben Lechuga) for collecting the data. Rui Coelho is supported by an Investigador-FCT contract from the Portuguese Foundation for Science and Technology (FCT) supported by the EU European Social Fund and the Programa Operacional Potencial Humano (Ref: IF/00253/2014).

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Table 1. Correlation coefficients between the annual catch of BFT in weight and the different management actions, including fishing effort in the Mediterranean (measured in allowable fishing months per year) and MLS and Sea surface temperature (SST). Three correlation coefficients are presented, specifically the Pearson product-moment, the Spearman's rank and the Kendall's rank.

	Pearson		Spearman		Kendall	
	r	p-value	r	rho	tau	p-value
Purse-seine	-0.41	< 0.001*	-0.53	< 0.001*	-0.41	< 0.001*
Longline	-0.32	0.003*	-0.40	< 0.001*	-0.31	<0.001*
Baitboat	-0.37	<0.001*	-0.51	< 0.001*	-0.41	< 0.001*
MLS	0.33	0.003*	0.43	< 0.001*	0.35	< 0.001*
SST	0.05	0.684	0.06	0.573	0.05	0.506

*: significant correlations with p-value < 0.05

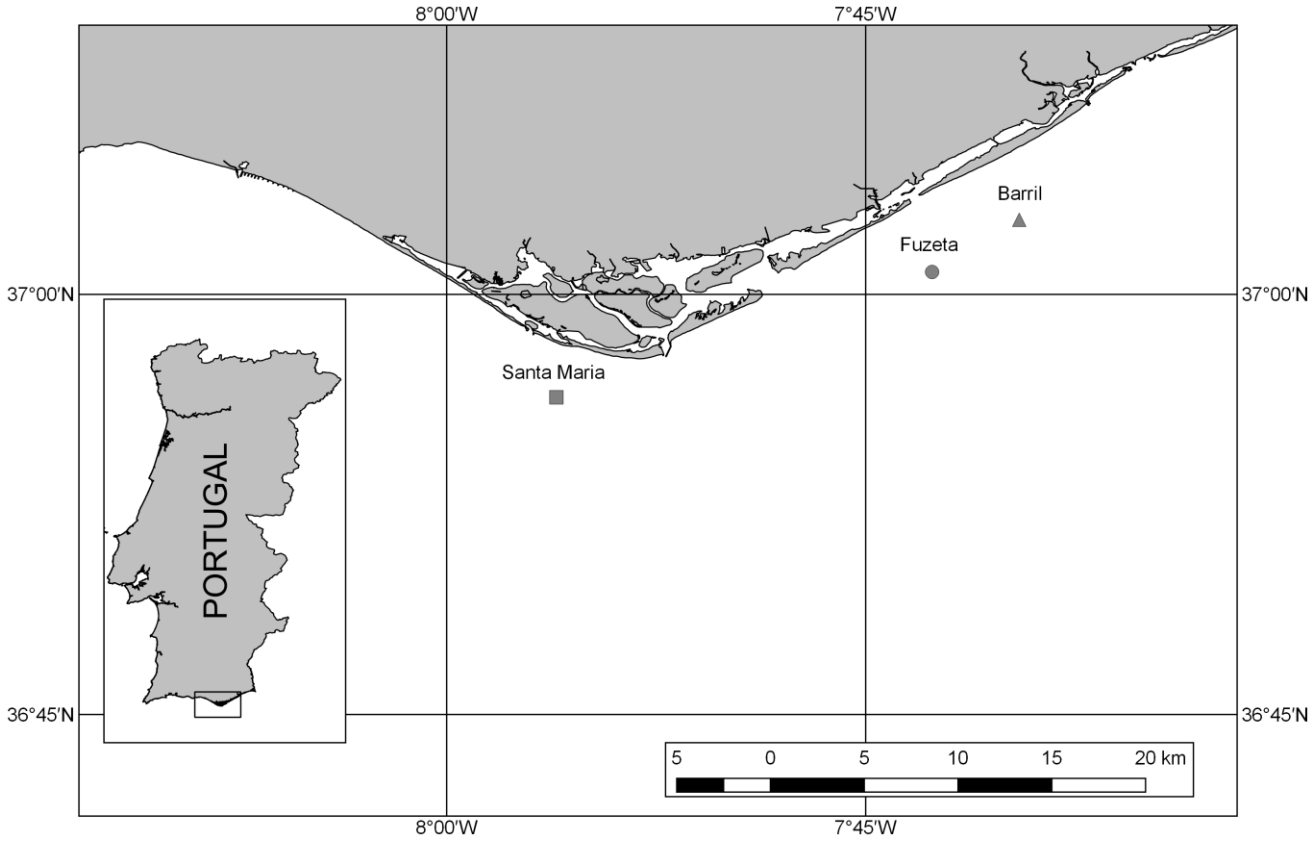


Figure 1. Location of the Algarve tuna traps.

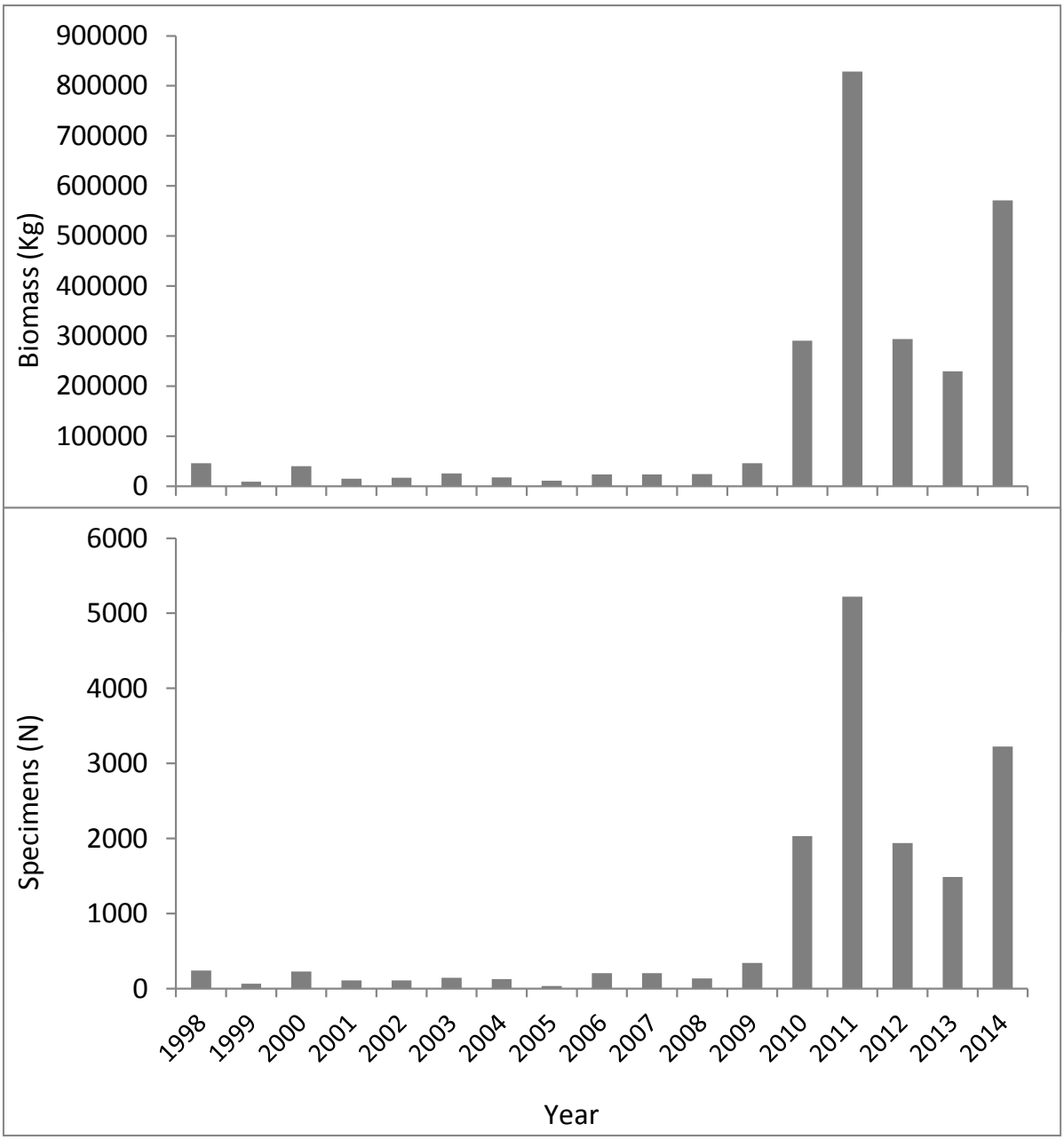
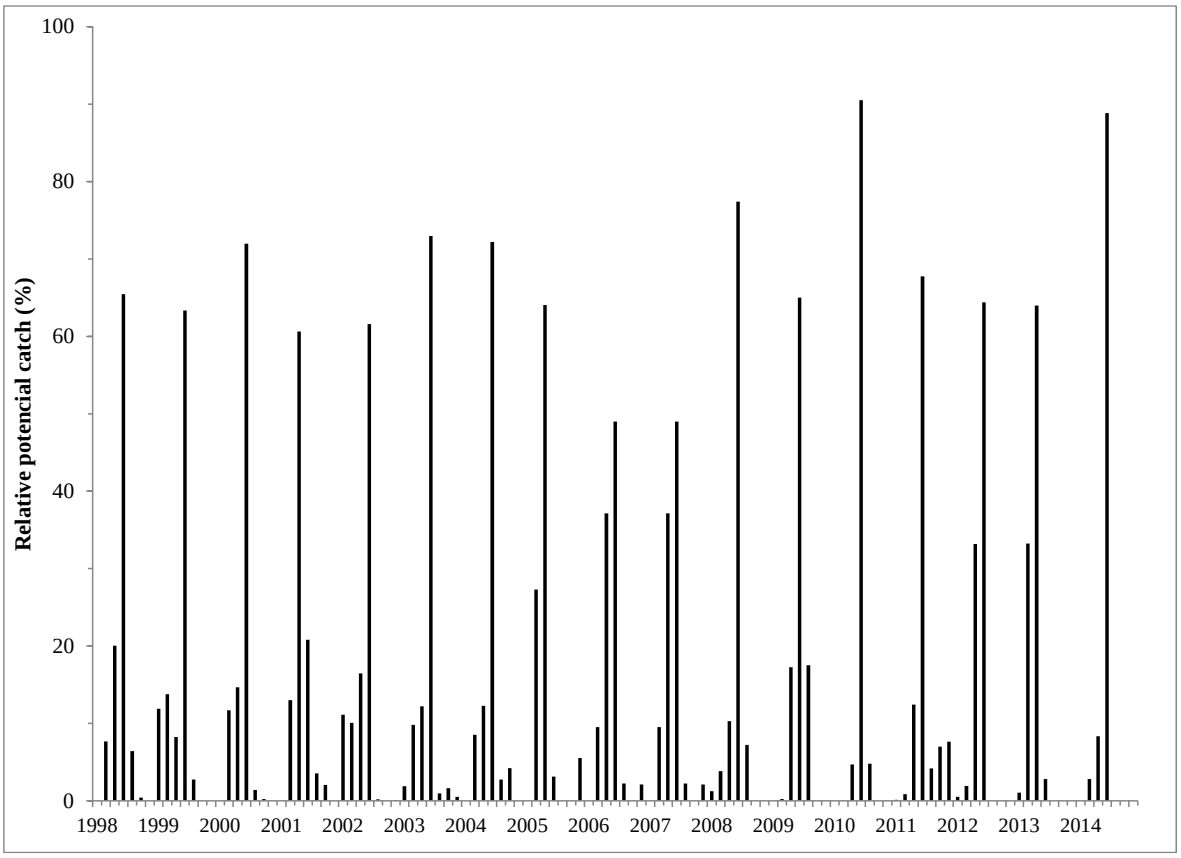


Figure 2. Estimated potential annual catches [i.e. observed catches + estimated biomass (top) and number (bottom) of live released fish] of bluefin tuna for the southeastern tuna traps (Fuzeta and Barril) off Algarve (Portugal) between 1998 and 2014. Estimations based on scientific observer's reports, between April and the 15th of July of each year.



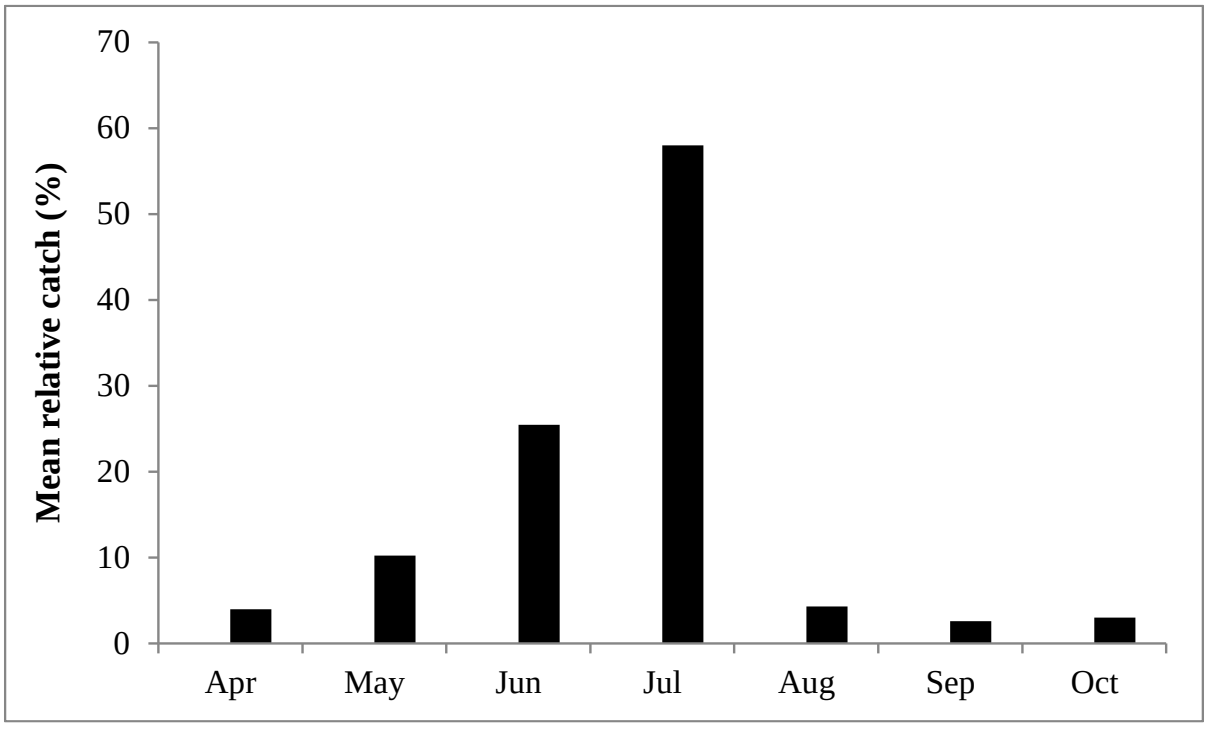


Figure 3. Monthly relative catches (%) of BFT in the tuna traps off southern Portugal between 1998 and 2014 (top). The bottom figure shows the mean monthly relative catch observed in the same period.

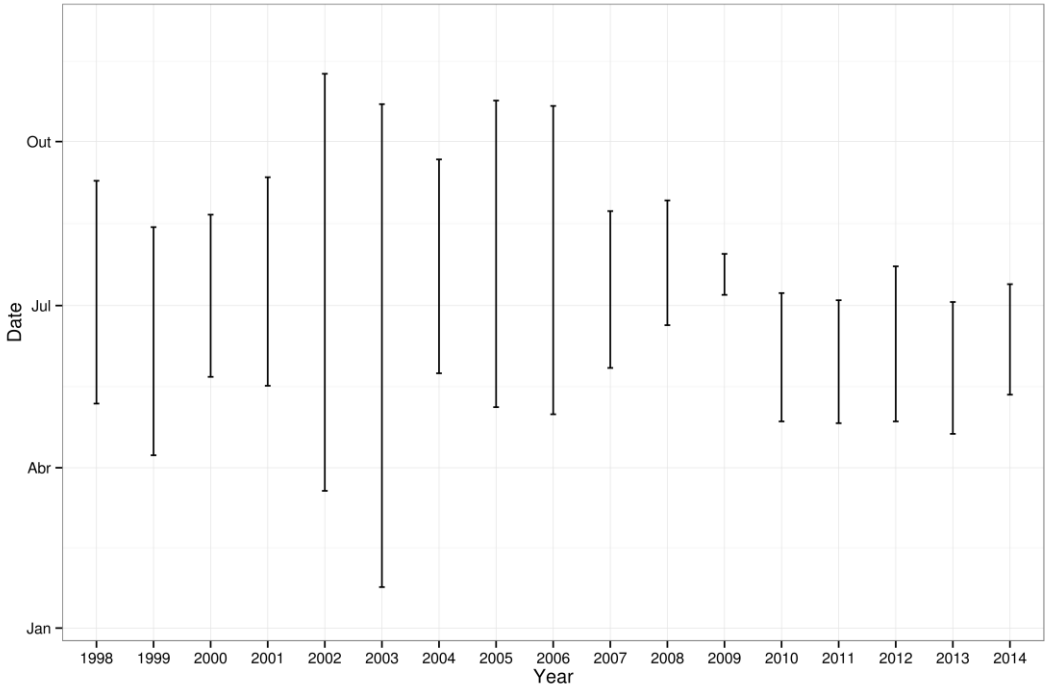


Figure 4. Annual period of activity of the tuna traps targeting bluefin tuna along the time series. Strong recruitment of mussels on the trap nets in 2009, obliged to late setting and earlier removal of the nets.

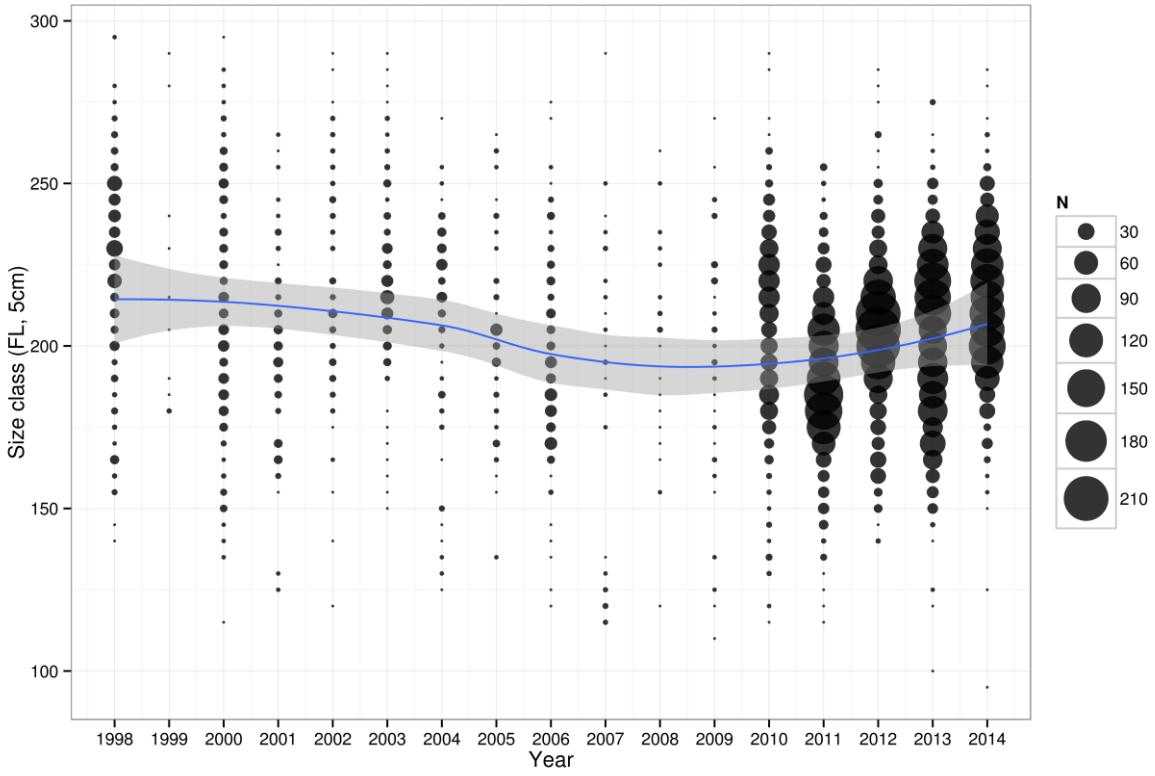


Figure 5. Annual size distribution of the captured bluefin tuna (by 5 cm FL size classes) along the study period (1998 to 2014), with a Loess (locally weighted scatterplot smoothing) regression line and the respective 95% confidence intervals (grey shadow. Fish less than 30Kg were not included for this analysis.

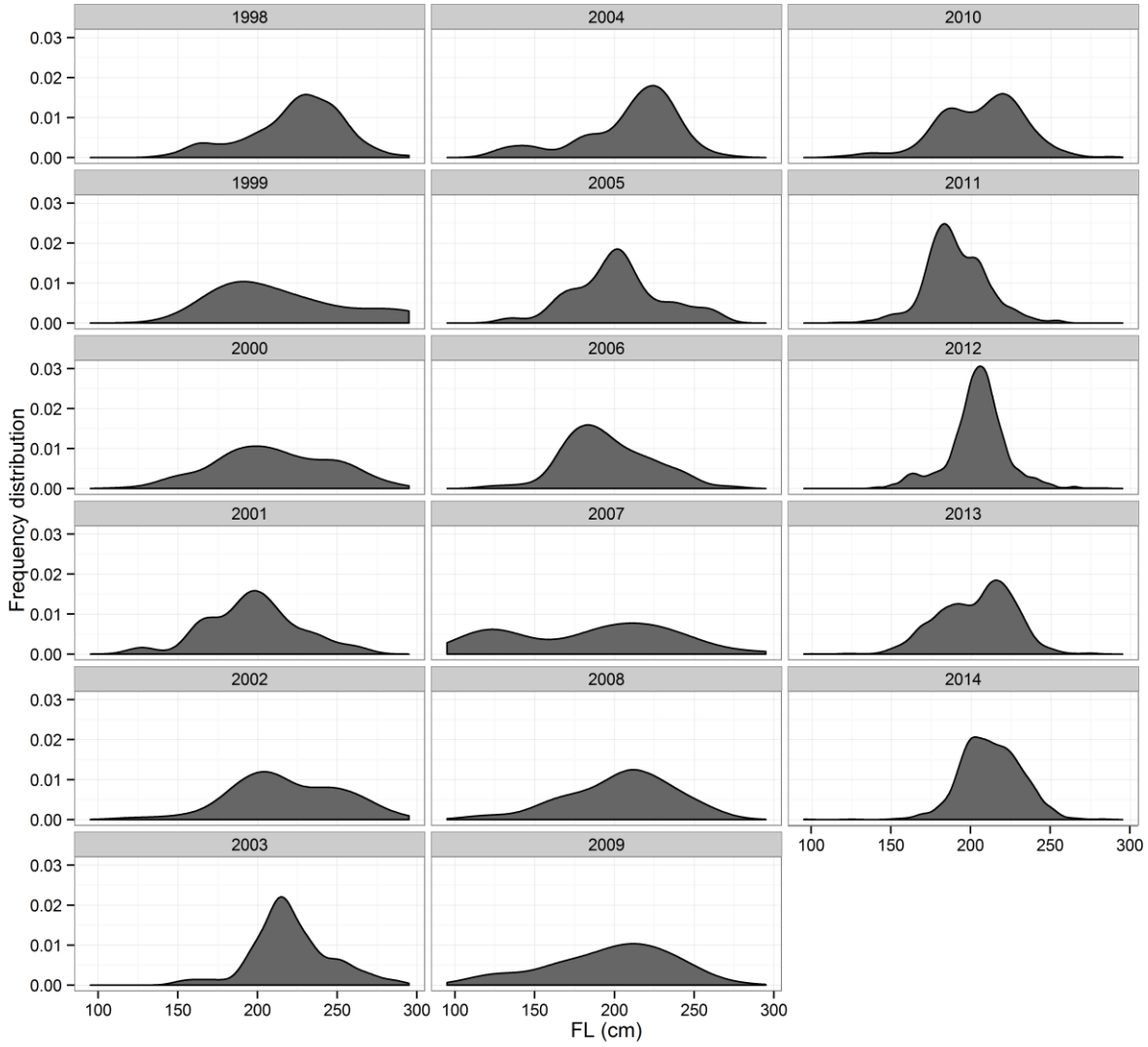


Figure 6. Yearly size frequency distribution of bluefin tuna (by 5 cm FL size classes) caught in the tuna traps off the Algarve between 1998 and 2014. Fish less than 30Kg were not included for this analysis.

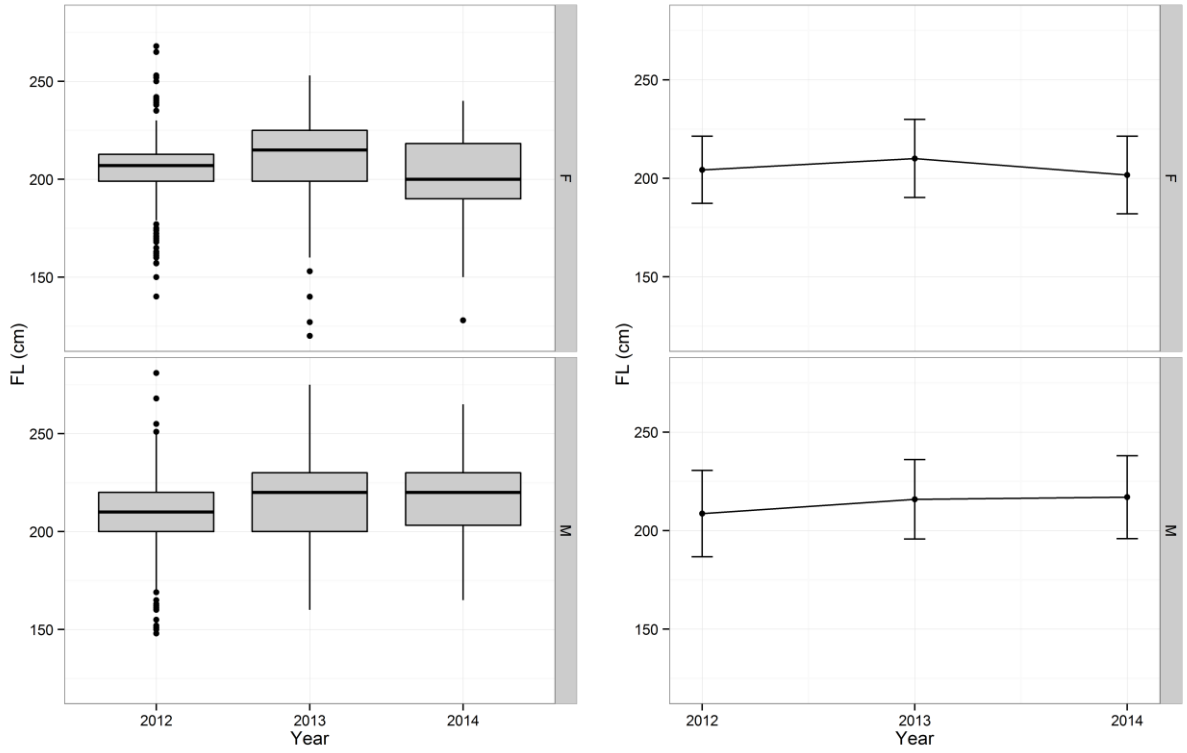


Figure 7. Sex-specific yearly catch-at-size of BFT caught in the tuna traps off the Algarve between 1998 and 2013, represented as boxplots with the median, inter-quartile range and range (left) and as the yearly averages with ± standard deviation (right). Fish less than 30Kg were not considered for this analysis. Sex-specific data is only available for the more recent years (2012 to 2014). The sex specific sample (1,528 specimens) represents 37% of the total trap catch (in number) during that period.

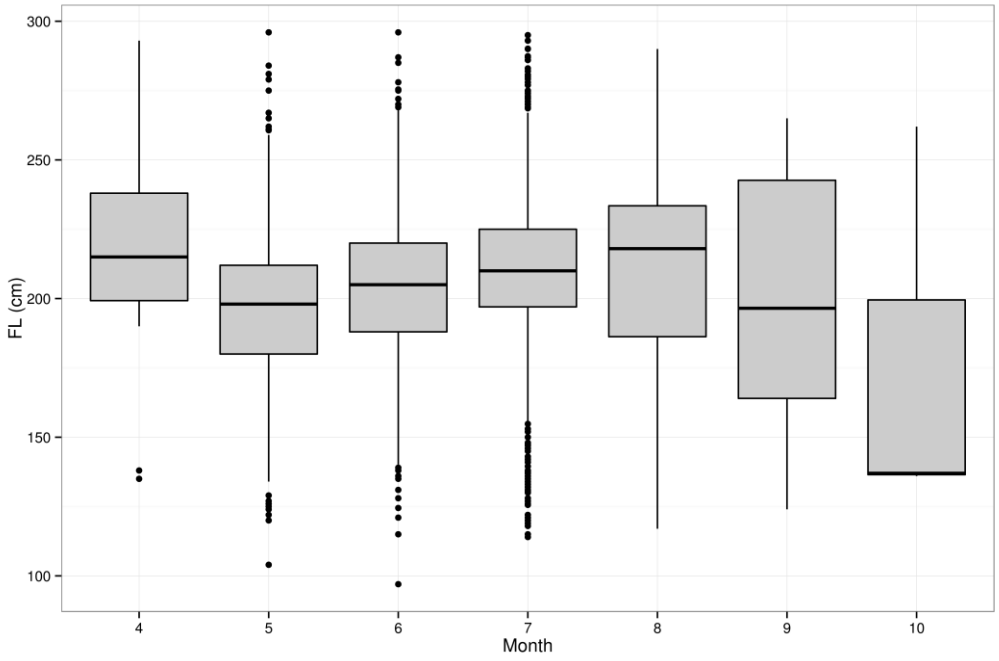


Figure 8. Monthly sizes of BFT caught in the tuna trap off the Algarve, represented as boxplots with the median, inter-quartile range. Data between the years 1998 and 2014 was pooled per month. Fish less than 30Kg were not considered for this analysis.

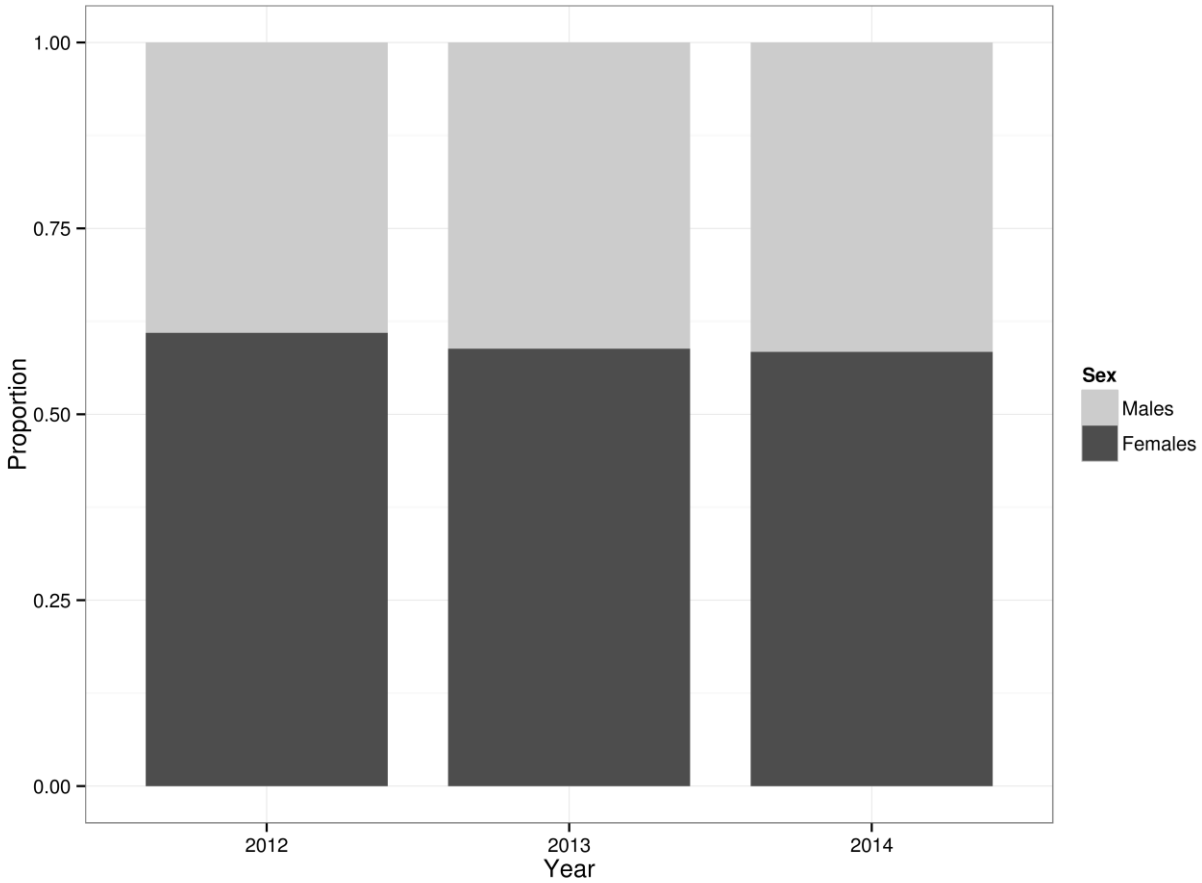


Figure 9. Yearly sex-ratios of BFT captured in the Algarve tuna traps in 2012 and 2014. The sex specific sample (1,528 specimens) represents 37% of the total trap catch (in number) during that period.

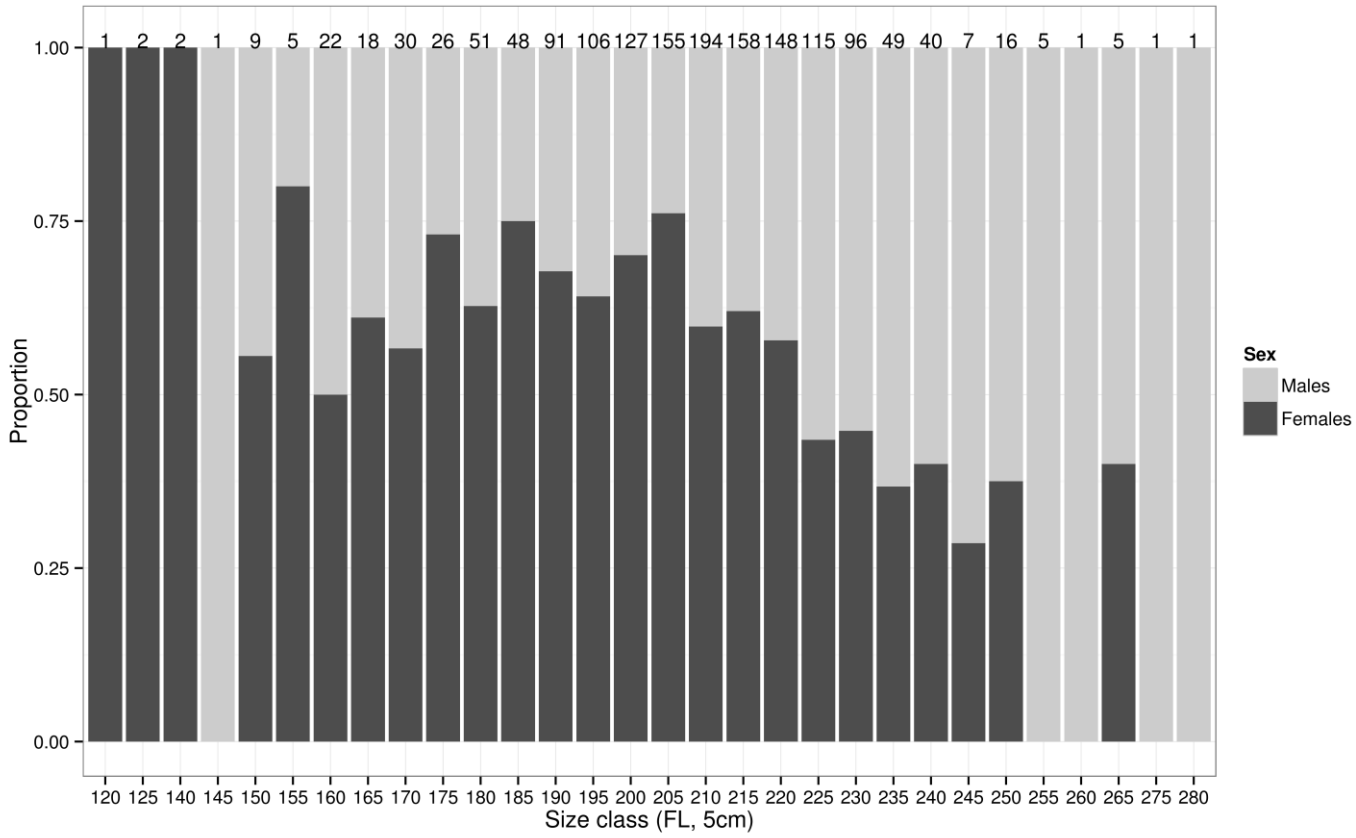


Figure 10. Sex-ratios by size classes (5cm FL) of the BFT captured in the Algarve tuna traps between 2012 and 2014. The sex specific sample (1,528 specimens) represents 37% of the total trap catch (in number) during that period. The figures at the top represent the number of specimens sampled per 5 cm FL size classes.