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Distribution patterns and indicators of the smooth hammerhead shark (*Sphyrna zygaena*) in the Atlantic Ocean

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Abstract

The smooth hammerhead shark, *Sphyrna zygaena*, is a pelagic shark occasionally captured as bycatch by industrial pelagic longline fleets in the Atlantic Ocean. Data for this study were collected by fishery observers, between 2003 and 2016. Datasets analyzed included information on catches per unit effort (CPUE), size and sex of smooth hammerhead sharks bycaught by the Portuguese pelagic longline fishery in the Atlantic Ocean. A total effort of 2 523 288 hooks yielded 638 sharks, ranging in size from 123–275 cm fork length. Larger sharks tended to occur in open ocean habitats and smaller specimens in coastal areas. Results confirmed the wide latitudinal range of the species (45°N–35°S), although CPUE was higher closer inshore within the Tropical North and Equatorial regions. An overall sex ratio of 1.4 males for each female was observed, with more males in both inshore and offshore waters. Significant differences in CPUE and size distribution were found between regions, years and quarters of the year. Mean CPUE increased and mean specimen size decreased in the Equatorial region from 2012 onwards. In order to remove fishery-dependent effects from CPUE data, a Tweedie Generalized Linear Model (GLM) was used to create a relative index of abundance (standardized CPUE). The index showed some oscillations in the initial years (2008–2010), followed by a decreasing trend until 2013 and then an increasing trend in more recent years, until 2016. The distributional patterns and indicators presented in this study provide a better understanding of the smooth hammerhead shark's spatio-temporal dynamics and population structure in the Atlantic Ocean and can be used to improve management and conservation measures for this species.

Keywords: pelagic sharks; spatial distribution; size distribution; fisheries; generalized linear model

1. Introduction

The smooth hammerhead shark (*Sphyrna zygaena*), is a widespread pelagic species that occurs in temperate and tropical waters, from latitudes of about 60°N to 55°S (Compagno, 1984; Casper *et al*., 2005). This species generally occurs close inshore, however it may also be found over continental and insular shelves to offshore areas, being described as the most oceanic of the hammerhead species (Compagno, 1984; Bester, 2008; Clarke *et al*., 2015).

Like other pelagic species, smooth hammerhead shark is a frequent bycatch in pelagic longline fisheries, although in much lower numbers in comparison to blue shark (*Prionace glauca*) and shortfin mako shark (*Isurus oxyrinchus*) (Buencuerpo *et al*., 1998; Cortés *et al*., 2010). Nevertheless, the population structure of the species remains unclear, as the available information is still very limited (Coelho *et al*., 2011). Moreover, this problem is aggravated by the lack of reliable species-specific data, since hammerhead sharks are often recorded together under the category *Sphyrna* spp. or included in the general sharks group (Camhi *et al*., 2009).

The International Commission for the Conservation of Atlantic Tunas (ICCAT) is the Regional Fisheries Management Organization (RFMO) responsible for the management and conservation of migratory tunas and tuna-like species (including pelagic sharks, such as smooth hammerhead shark) in the Atlantic Ocean and adjacent seas. In 2010, ICCAT adopted several management recommendations to protect smooth hammerhead shark and stated the need of research focused on hammerhead sharks in the Convention area (ICCAT, 2010). Cortés *et al*. (2010) conducted an Ecological Risk Assessment for eleven species of pelagic elasmobranchs, concluding that smooth hammerhead shark was amongst the less vulnerable to overexploitation by pelagic longline fisheries in the Convention area. This was mainly due to a relatively high productivity compared to other pelagic sharks. The smooth hammerhead showed also relatively low interaction with pelagic fisheries, as the species spends part of its life cycle in coastal waters and is therefore less susceptible to capture in those oceanic fisheries. However, Cortés *et al*. (2010) highlighted the urgent need for better biological and distributional information, since there was a high level of uncertainty regarding the life cycle parameters and distribution patterns of this species.

Studying spatio-temporal dynamics and population structure of marine species is required to better understand distribution patterns of species and predict potential fishing impacts. This information is therefore crucial for the development of effective fisheries management and conservation strategies. Whilst some recent studies have shown evidence of probable severe decline in the global population of smooth hammerhead shark (Baum *et al.* 2003; Myers *et al.* 2007; Ferretti *et al.* 2008), these findings may not represent a full and accurate portrayal of the species' status, as many were based on limited data from logbooks, surveys and public sighting records, which may not adequately sample the smooth hammerhead shark population. In fact, several flaws were identified, mostly related to insufficient sample sizes, poor geographical coverage, misidentification of the species and oversight of the fishing gear specifications and modifications through time (Burgess *et al.*, 2005).

The general objective of this study was to provide information on the distributional patterns and indicators of relative abundance of smooth hammerhead shark aiming to fill knowledge gaps for the species in the Atlantic Ocean. Specific objectives of the study were to analyze the catch per unit effort (CPUE), size and sex ratio distribution, provide time series trends, and analyze the seasonal patterns of CPUE and size distributions of smooth hammerhead shark in the Atlantic Ocean.

2. Material and methods

2.1. Data collection

Data were collected across the Atlantic Ocean by scientific fishery observers from the Portuguese Institute for the Ocean and Atmosphere (IPMA) onboard Portuguese pelagic longline vessels. This fleet operates throughout a wide area of the Atlantic Ocean, with spots of high fishing effort around the temperate Northeast and Equatorial regions in oceanic waters. The spatial distribution of the fishing effort is associated with the target species - swordfish (*Xiphias gladius*) and, to a lesser extent, blue shark -, although the characteristics of the vessels of the fleet differ between regions. For example, the vessels operating in the Northeast region of the Atlantic (closer to mainland Portugal and the Azores archipelago) are usually smaller in size and mostly do not have freezer. In contrast, the vessels that concentrate their activity in more distant regions of the equatorial Atlantic are usually larger vessels that can freeze catches (Coelho *et al.*, 2012). The fishing gear typically used by the Portuguese fleet consists of a standard monofilament polyamide mainline set for fishing at depths of 30–70 m. The main line is usually set with five branch lines between pairs of buoys, with each branch line being approximately 18 m in length and a hook in the terminal tackle. The hooks used by the fleet are typically stainless-steel J-style hooks, baited either with squid (*Illex* spp.) or mackerel (*Scomber* spp.). Both monofilament and multifilament wire branch lines are used, but only one type is used per fishing set. Gear deployment traditionally begins at around 17:00, with haulback starting the next day from about 06:00.

Between 2003 and 2016, data from a total of 2110 longline sets were collected, which amounted to a total effort of 2 523 288 hooks and yielded 638 smooth hammerhead sharks. The spatial distribution of the sampled areas ranged from 45°N–35°S (lat) and 45ºW–10ºE (long).

For all specimens caught, fishery observers recorded data on fork length (FL), sex, capture location (latitude and longitude), water temperature and date. Catch and effort data were available from 2003–2016, while data on smooth hammerhead shark size and sex were available from 2006–2015.

2.2. Data analysis

Catch per unit effort (number of specimens caught /1000 hooks), effort (total number of hooks per set) and sex ratio distributions were calculated and expressed geographically using 5° x 5° resolution grids of latitude and longitude (e.g., see Lee *et al.*, 2005; Fernandez-Carvalho *et al.*, 2015).

Catch per unit effort and size data were tested for normality using the Kolmogorov-Smirnov normality test with the Lilliefors correction (Lilliefors, 1967), and for homogeneity of variances with the Levene test (Levene, 1960). Given the lack of normality in the data and heterogeneity of variances, CPUE and specimen size were compared between years, quarters of the year (1st: January-March, 2nd: April-June, 3rd: July-September, 4th: October-December) and regions with nonparametric Kruskal–Wallis tests, Wilcoxon-Man-Whitney tests and k-sample permutation tests using the permutational central limit theorem (Manly, 2007). Sex ratios were compared among regions with contingency tables and Pearson's Chi-squared tests.

Catches were mainly composed of specimens captured in the Equatorial and Tropical North regions of the Atlantic Ocean, hence only these two regions were considered for the sex ratio analysis and for the calculation of yearly/quarterly CPUE and specimen size. The Tropical North region was delimited from 10–30°N, while the Equatorial region extended from 10°N to 10°S.

A Generalized Linear Model (GLM) was used to standardize the CPUE time series. By performing a standardization of CPUE, the effects of the covariates considered are removed from CPUE values and those standardized CPUE can then be used as annual indices of abundance. For the CPUE standardization, the response variable considered was CPUE measured as number of individuals caught per 1000 hooks deployed. In the Tropical North and Equatorial regions, the available catch data started in 2005 and was available until 2016. However, data for 2005–2007 were not used in the GLM because there was limited information in that period. As smooth hammerhead shark is a bycatch from the fishery, there were many fishing sets with zero catches, resulting in a response variable of CPUE=0. As these zeros can cause mathematical problems for fitting the models, we carried out the CPUE standardization using the Tweedie distribution model (Tweedie, 1984). The Tweedie distribution is part of the exponential family of distributions and is defined by a mean (μ) and a variance (φμp), in which φ is the dispersion parameter and p is an index parameter. In this study, the index parameter (p-index) was calculated by maximum likelihood estimation (MLE). The explanatory variables considered and tested in the model were: Year (2008–2016), Month (January–December) and Area (three areas selected using a GLM-tree area stratification based on the approach of Ichinokawa and Brodziak (2010; Figure 1). The significance of the explanatory variables in the CPUE standardization model was assessed with likelihood ratio tests comparing each univariate model to the null model (considering a significance level of 5%), and by analyzing the deviance explained by each explanatory variable. Goodness-of-fit and model comparison was carried out with the Akaike Information Criteria (AIC) and the pseudo coefficient of determination (R^2). Model validation was carried out with a residual analysis. The final relative index of abundance was estimated by calculating the marginal means of the year factor, also called least square means (LSmeans).

All statistical analyses in this work were carried out with the R Project for Statistical Computing version 3.3.2 (R Core Team, 2016). Plots were obtained using library "ggplot2" (Wickham, 2009) and maps drawn using libraries "mapplots" (Gerritsen, 2014) and "shapefiles" (Stabler, 2013). Additional libraries used in the GLM analysis included "tweedie" (Dunn, 2014), "statmod" (Smyth *et al.*, 2015) and "lsmeans" (Lenth, 2015).

3. Results

3.1. CPUE distribution

The spatial distribution of the sampled fishing sets showed that the fishing effort sampled over the 14-year period took place between approximately 50°N and 40°S (Figure 2). The temperate Northeast (30–45°N) and the Equatorial (10°N–5°S) regions represented the major areas of operation of the Portuguese pelagic longline fleet in the Atlantic Ocean, with fishing effort highest in the offshore waters of these regions. The fishing effort ranged between 668 and 2300 hooks per set, with an average effort of 1196 hooks per set.

Nominal CPUE ranged from 0.0 to 8.61, with an average CPUE of 0.24. Most sets (85%) showed zero smooth hammerhead shark catches, whilst 13 % had a CPUE between 1 and 3, and 2% had a CPUE of 4 or more. The geographic distribution of CPUE indicated that smooth hammerhead sharks were distributed widely in the Atlantic Ocean, from 45°N to 35°S (Figure 3), although fishing effort was less at higher latitudes. Nevertheless, higher CPUE values were found closer to the African continent, within both the Tropical North and Equatorial regions.

3.2. Size distribution

Fishery observers recorded data on specimen size for 559 sharks (including juveniles and adults) caught between ca. 40°N and 30°S (Figure 4). The overall length range was 123–275 cm FL, with a mean size of 195 cm FL. Typically, larger-sized specimens were caught offshore, and smaller-sized specimens caught in more inshore waters, particularly in the Gulf of Guinea. Furthermore, all specimens caught in the offshore waters of the South Atlantic (15–30°S) were 187 cm FL or larger.

3.3. Sex ratio distribution

Data on sex was recorded for 562 specimens, caught between ca. 40°N and 30°S, of which 238 (42.3%) were female and 324 (57.7%) were male (Figure 5). The overall sex ratio was 1.4 males for each female. Particularly, there seemed to be some evidence of the presence of more males in both inshore and offshore waters of the Atlantic Ocean.

The differences observed when comparing the Equatorial and Tropical North regions of the Atlantic Ocean were not statistically significant (proportion test: Chi-squared = 0.541, df = 1, p-value = 0.462).

3.4. Yearly and quarterly trends in CPUE

Catch per unit effort was not normally distributed (Lilliefors test: D = 0.501, p value < 0.001). Variances were heterogeneous between years (Levene test: F = 7.121, df = 10, p value < 0.001) and quarters of the year (Levene test: F = 19.031, df = 3, p value < 0.001) and homogenous between regions (Levene test: F = 3.854, df = 1, p value = 0.050). Univariate nonparametric statistical tests revealed that CPUE was significantly different between years (K–W: Chi-squared = 124.86, df = 10, p-value < 0.001; permutation test: Chi-squared = 67.67, df = 10, p-value <

0.001) and quarters of the year (K–W: Chi-squared = 100.89, df = 3, p-value < 0.001; permutation test: Chi-squared = 54.57, df = 3, p-value < 0.001). The differences between regions were less clear, as the differences were statistically significant when using Wilcoxon-Man-Whitney tests (W-M-W: W = 117870, p-value < 0.001) but not when using permutation tests (permutation test: Chi-squared = 3.85, df = 1, p-value = 0.050).

The mean annual CPUE trend followed an oscillatory pattern in both the Tropical North and Equatorial regions (Figure 6), with no catches recorded in 2007. The mean CPUE values were generally lower in the Equatorial region than in the Tropical North region. The mean CPUE tended to increase from 2012 onwards in the Equatorial region, with a recent increase in CPUE also observed for the Tropical North region. Seasonality also seemed to influence CPUE (Figure 7). Higher mean CPUE values were recorded in the 3rd quarter of year for the Equatorial region. In the Tropical North, mean CPUE tended to increase over the year, reaching a peak in the 4th quarter.

3.5. Yearly and quarterly trends in the size distribution

Size data were not normally distributed (Lilliefors test: D = 0.059, p value < 0.001) and variances were heterogeneous between years (Levene test: F = 6.988, df = 8, p value < 0.001) and quarters of the year (Levene test: F = 4.8207, df = 3, p value<0.01), but not between regions (Levene test: F = 2.774, df = 1, p value = 0.096). Sizes were compared with univariate nonparametric statistical tests among years (K–W: Chi-squared = 101.74, df = 8, p-value < 0.001; permutation test: Chi-squared = 100.94, df = 8, p-value < 0.001), quarters of the year (K–W: Chi-squared = 14.737, df = 3, p-value < 0.01; permutation test: Chi-squared = 18.987, df = 3, p-value < 0.001) and regions (W-M-W: W = 23964, p-value < 0.001; permutation test: Chi-squared = 25.81, df = 1, p-value < 0.001), with statistical differences detected for all cases.

The time series of the mean size distribution showed a persistent decreasing trend in fork length in the Equatorial region from 2012 onwards (Figure 8). Whilst length data were more variable in the Tropical North Atlantic, it should be noted that only single specimens were measured in 2009 and 2015 for this region, and no size data were recorded in 2007, 2013 and 2014. In terms of seasonality, mean sizes were higher and more regular in the Tropical North region in comparison to the Equatorial region, although size data were lacking for the 2nd quarter of the year in the Tropical North region (Figure 9).

3.6. Relative index of abundance

The Tweedie GLM used in the CPUE standardization explained approximately 32% of the variability. The index parameter estimated for the Tweedie distribution was 1.155 and resulted in a distribution that expects 70.4% of zeros, compared to the 75.2% in smooth hammerhead shark CPUE data. All explanatory variables tested (year, month and area effects) contributed significantly for explaining part of the deviance. Seasonal effects were responsible for most of the variability, followed by year effects and finally area effects (Table 1).

The final relative index of abundance showed an oscillatory trend in the initial years between 2008 and 2010, followed by a decrease in the period between 2010 and 2013. In more recent years, between 2013 and 2016, results showed an increasing tendency in the standardized CPUE series (Figure 10). In general, nominal CPUE and standardized CPUE produced similar trends from 2010 onwards (Figure 10). This final model revealed no problems or outliers in terms of residual analysis (see Supplementary Material).

4. Discussion

In light of the global declining trends of several shark stocks, improving the limited information available for smooth hammerhead shark becomes critical for the species conservation and fisheries management. This work provides detailed information on the spatio-temporal dynamics and population structure of smooth hammerhead shark in the Atlantic Ocean. Catch per unit effort, catch at size and sex ratio distributions were analyzed based on detailed data collected by fishery observers onboard Portuguese pelagic longline vessels operating in the Atlantic Ocean, between 2003 and 2016. In addition, time series trends and seasonal patterns of CPUE and size distributions were analyzed.

In terms of the spatial distribution of CPUE, records of catches ranging from 45°N to 35°S were observed, confirming the wide latitudinal range of this species in the Atlantic Ocean (Compagno, 1984; Cortés *et al*., 2015). Higher CPUE was found closer inshore in both the Tropical North and Equatorial regions. Within these regions, the African west coast (including the Gulf of Guinea) represented an important area of high CPUE. Near-shore waters, as well as islands and seamounts, tend to be sites where many shark species aggregate, and may be used as nursery areas, feeding grounds and/or shelter sites (Olson *et al*., 1994; Castro *et al*., 1995; Beck *et al*., 2001; Queiroz *et al*., 2012; Knip *et al*., 2010). In addition, smooth hammerhead sharks are reported to occur generally close inshore and in shallow waters, and the Gulf of Guinea is thought to be a possible nursery area for this species (Compagno, 1984; Bester, 2008; Castro *et al*., 1995). Consequently, the spatial distribution of CPUE is possibly related to environmental conditions off the African west coast and the habitat preferences of the species. Moreover, it is important to highlight that a high percentage of the sets showed zero catches of smooth hammerhead sharks, which may support previous results by Cortés *et al*. (2010) that demonstrated smooth hammerhead shark to be one of the less vulnerable shark species to pelagic longline fisheries in the Atlantic Ocean, due to reduced interactions with the fishing gear.

The specimens caught ranged in size from 123–275 cm FL. Larger sharks tended to occur in the open ocean habitat, while smaller-sized specimens seemed to concentrate in more coastal areas. This distribution pattern may be linked to habitat characteristics and migratory behavior, which are in turn related to growth and reproductive state (Coelho *et al*., 2018). Another possible hypothesis for the size distribution observed is that it may also be affected by fishing gear selectivity (Fernandez-Carvalho *et al*., 2015). However, the fishing gear analyzed was always shallow pelagic longline sets targeting swordfish, without likely size selectivity issues. Thus, the hypothesis that it relates to life history stages, with the occurrence of smaller specimens in more inshore waters and larger specimens in more oceanic waters, is more likely.

In general, the sex ratio data indicated that there was a tendency for the presence of more males in the sampled area, representing an overall sex ratio of 1.4 males for each female. The predominance of one sex over the other in fishery catches may be related to selectivity of the fishing gear, through greater attraction to bait and/or larger sizes (White *et al*., 2008). Also, partial segregation of sexes has been associated with differential selection of habitats for social, thermal or foraging reasons (Mucientes *et al*., 2009), which may explain the tendency for females to move to areas outside those in which this longline fleet tends to operate.

Since most specimens were captured in the Equatorial and Tropical North regions of the Atlantic Ocean, only data from specimens caught in those two regions were used in the detailed analyses of CPUE and size distributions. Significant differences in CPUE and size distributions were found between regions, years and quarters of the year.

Some previous studies suggested that the population of smooth hammerhead sharks in the Atlantic Ocean has likely experienced strong declines (Baum *et al*., 2003; Myers *et al*., 2007; Ferretti *et al*., 2008), however these previous findings have also been shown to not necessarily represent a full and accurate portrayal of the species' status (Burgess *et al*., 2005). From our results, it appears that there has been an increase in mean CPUE, along with a decrease of mean specimen size, in the Equatorial region from 2012 onwards. These results may be related to fishing pressure and the capture of larger specimens over the years, which would cause a decrease in the mean specimen size. Moreover, the standardized CPUE, which can be used as a regional indicator of relative abundance, was not much different from the nominal values, showing similar results and trends from 2010 onwards.

It is important to note, however, that the data used in our study may also not fully reflect the complete trends in the Atlantic population of smooth hammerhead shark, since data from only one pelagic longline fleet were considered (Maunder *et al*., 2006). The data came from oceanic pelagic longlines, set in oceanic waters and targeting mainly swordfish. As such, the results obtained provide mainly a snapshot of the population that is present in these waters and is selected by the shallow setting longline gear targeting mainly swordfish. Also, the possibility of occurrence of smooth hammerhead sharks in the areas not covered cannot be excluded.

Despite those limitations, inherent to the fishery-dependent nature of the data, the distribution patterns presented in our study provide an improved understanding of spatio-temporal dynamics and population structure of the smooth hammerhead shark in the Atlantic Ocean. Even though the smooth hammerhead shark is currently a no-retention species in most Atlantic fisheries (ICCAT, 2010), it is still captured as bycatch and discarded. The hooking mortality is known to be high (e.g., Coelho *et al.*, 2012), while the post-release mortality is largely unknown. As such, further work is needed to fill knowledge gaps, and better inform future management decisions and implement efficient conservation measures for this species.

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Tables

Table 1 - Deviance of the parameters used for the CPUE standardization with a Tweedie GLM.

Tweedie model (R^2=32%)

Parameter	Df	Deviance	Resid. Df	Resid. Dev.	Significance (p-value)
Null			973	1452	
Year	8	212	965	1240	< 0.01
Month	11	231	954	1009	< 0.01
Area	2	41	952	968	< 0.01

Deviance of the parameters used for the CPUE standardization with a Tweedie GLM. For each parameter it is indicated the degrees of freedom used, the deviance explained, the residual degrees of freedom, the deviance after incorporating each parameter and the significance (p-value) of each parameter. It is also indicated the coefficient of determination value (pseudo R^2).

Figure captions

Figure 1 - Spatial area stratification. Spatial area stratification for smooth hammerhead shark CPUE captured by the Portuguese pelagic longline fleet in the Tropical North and Equatorial regions of the Atlantic Ocean. 1, 2 and 3 are the labels of the final areas selected by the GLM-tree algorithm.

Figure 2 - Spatial distribution of the sampling effort. Spatial distribution of the sampling effort (fishing effort in number of hooks) analyzed for this work, from the Portuguese pelagic longline fleet in the Atlantic Ocean, between 2003 and 2016.

Figure 3 - Spatial distribution of the catch per unit effort. Spatial distribution of smooth hammerhead shark CPUE (n/1000 hooks) analyzed for this work, by the Portuguese pelagic longline fleet in the Atlantic Ocean, between 2003 and 2016.

Figure 4 - Location and size distribution of smooth hammerhead shark. Location and size distribution (FL, cm) of smooth hammerhead shark recorded for this study between 2006 and 2015. The color scale of the dots represents specimen sizes, with darker colors representing smaller specimens and lighter colors, larger specimens. The categorization of size classes was carried out using the 0.2 quantiles of the data (values in the legend represent the lower and upper limits of each size class).

Figure 5 - Sex ratios of smooth hammerhead shark. Sex ratios of smooth hammerhead shark, recorded in 5°x5° squares, between 2006 and 2015. The circle diameter is proportional to the sample size (N) in each square.

Figure 6 - Time series of the mean CPUE. Time series of the mean CPUE of smooth hammerhead shark, caught in the Tropical North and Equatorial regions of the Atlantic Ocean, between 2005 and 2016. Bars represent the ± standard error of the mean.

Figure 7 - Mean CPUE by quarter of the year. Mean CPUE of smooth hammerhead shark, caught in the Tropical North and Equatorial regions of the Atlantic Ocean during the four quarters of the year, between 2005 and 2016. Bars represent the ± standard error of the mean.

Figure 8 - Time series of the mean sizes. Time series of the mean sizes (FL, cm) of smooth hammerhead shark, caught in the Tropical North and Equatorial regions of the Atlantic Ocean, between 2006 and 2015. Numbers between brackets represent the sample size for each year. Bars represent the ± standard error of the mean.

Figure 9 - Mean sizes by quarter of the year. Mean sizes (FL, cm) of smooth hammerhead shark, caught in the Tropical North and Equatorial regions of the Atlantic Ocean during the four quarters of the year, between 2006 and 2015. Numbers between brackets represent the sample size for each quarter of the year. Bars represent the ± standard error of the mean.

Figure 10 - Results of the CPUE standardization with a Tweedie GLM. Results of the CPUE standardization with a Tweedie GLM (black line), that represents a relative index of abundance for smooth hammerhead shark, with the respective 95% confidence intervals (gray lines). The triangles represent the nominal CPUE series. The vertical dotted line symbolizes the entry into force of the ICCAT Recommendation on hammerhead sharks (ICCAT, 2010).

Figure 1

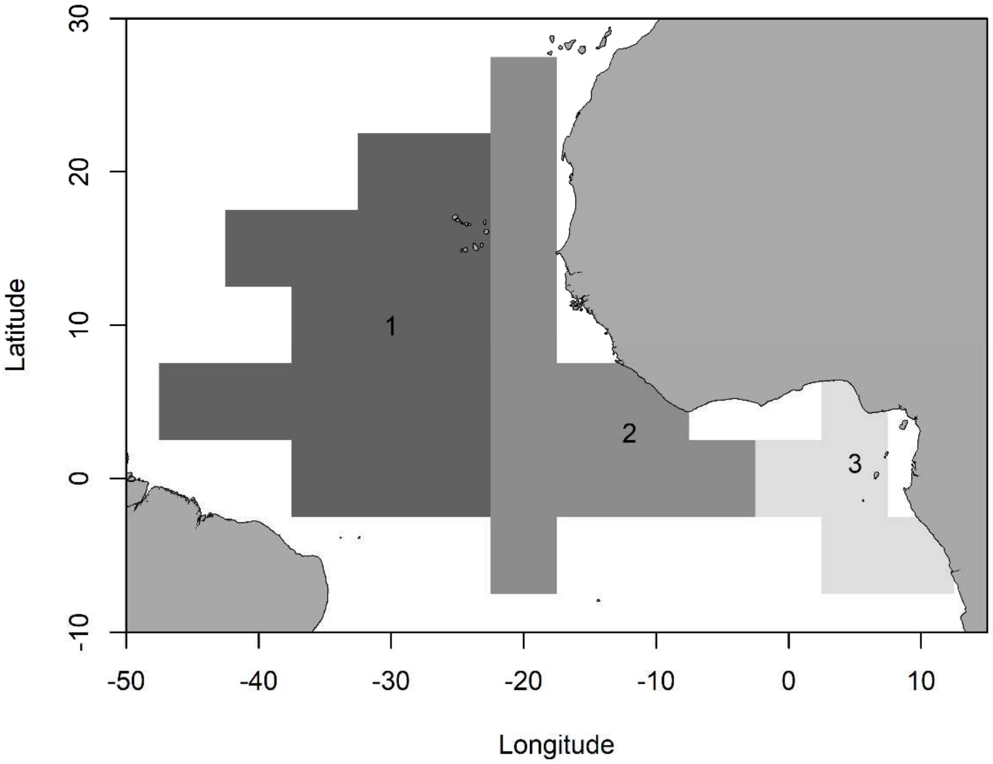


Figure 2

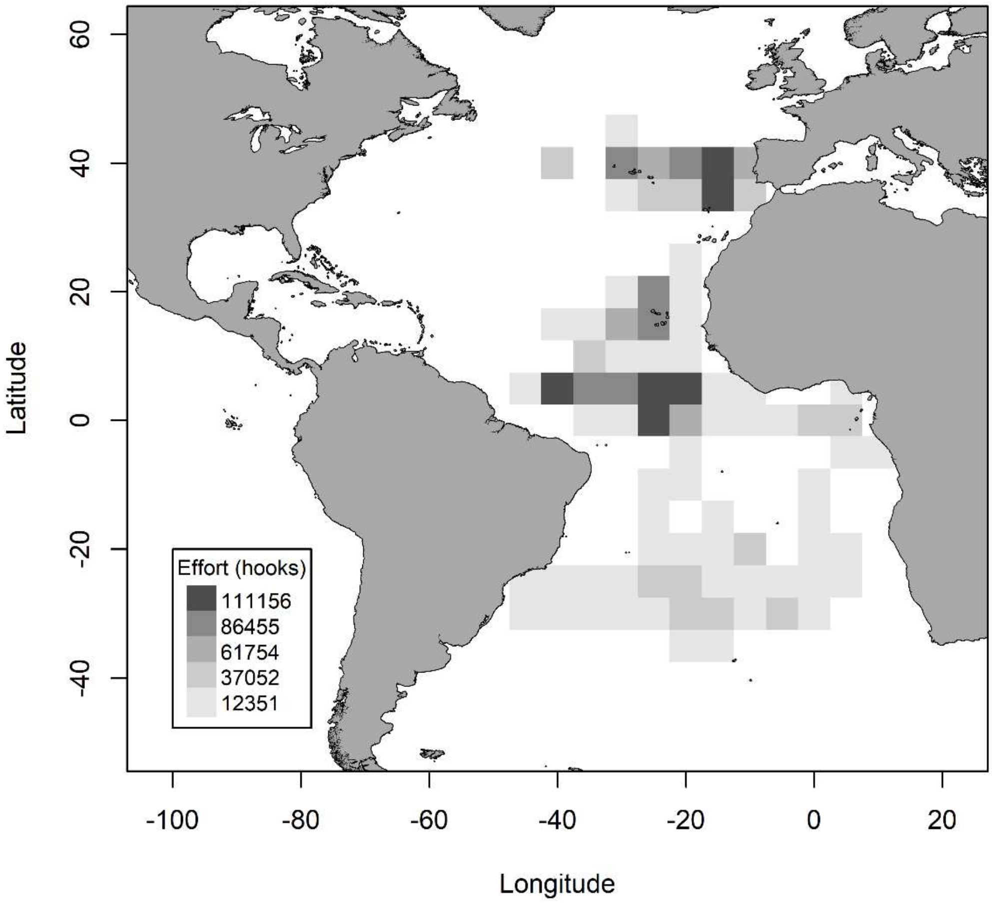

Effort (hooks)
111156
86455
61754
37052
12351
Latitude
60
40
20
0
-20
-40
Longitude
-100
-80
-60
-40
-20
0
20

Figure 3

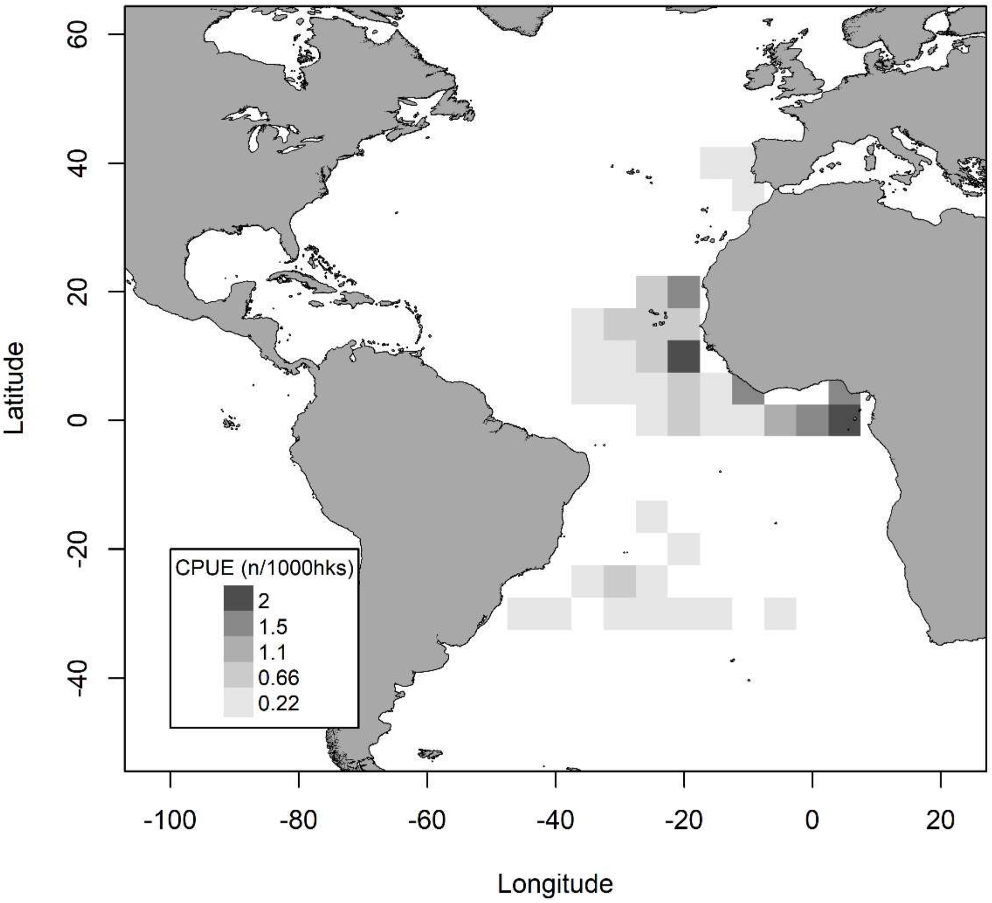

CPUE (n/1000hks)
2
1.5
1.1
0.66
0.22
Latitude
60
40
20
0
-20
-40
Longitude
-100
-80
-60
-40
-20
0
20

Figure 4

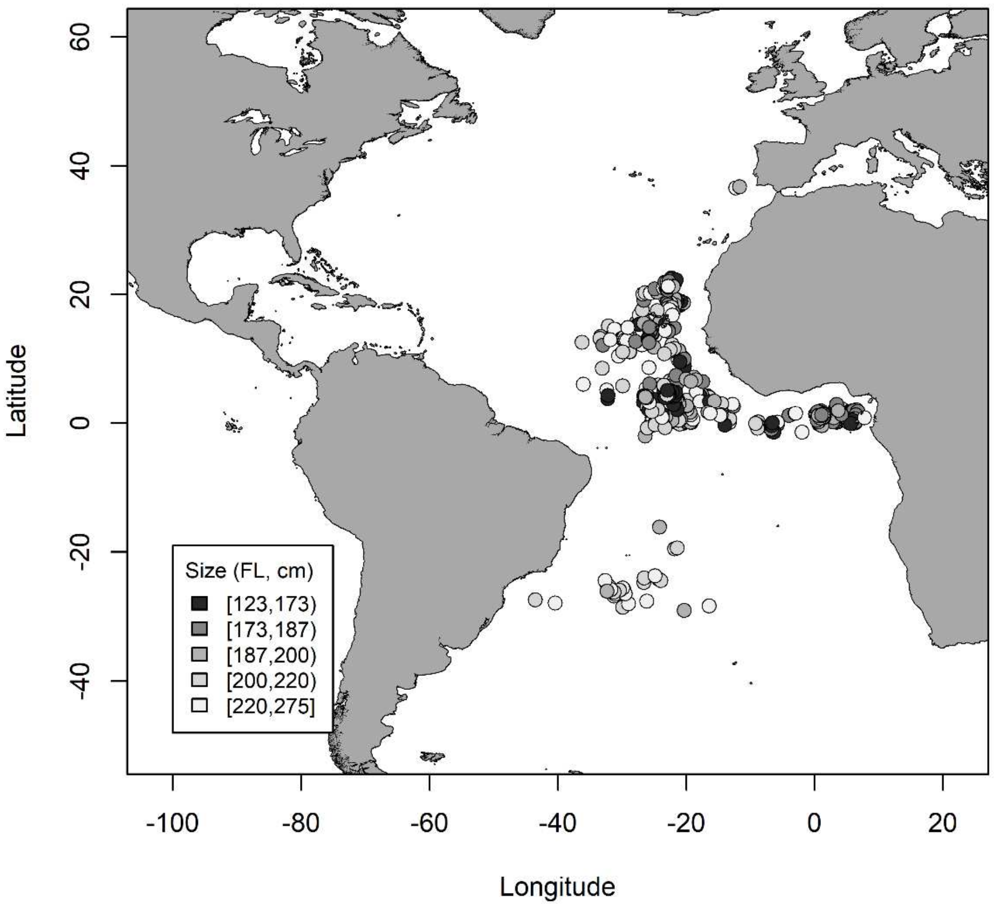

60
40
20
0
-20
-40
Latitude
-100
-80
-60
-40
-20
0
20
Longitude
Size (FL, cm)
[123,173)
[173,187)
[187,200)
[200,220)
[220,275]

Figure 5

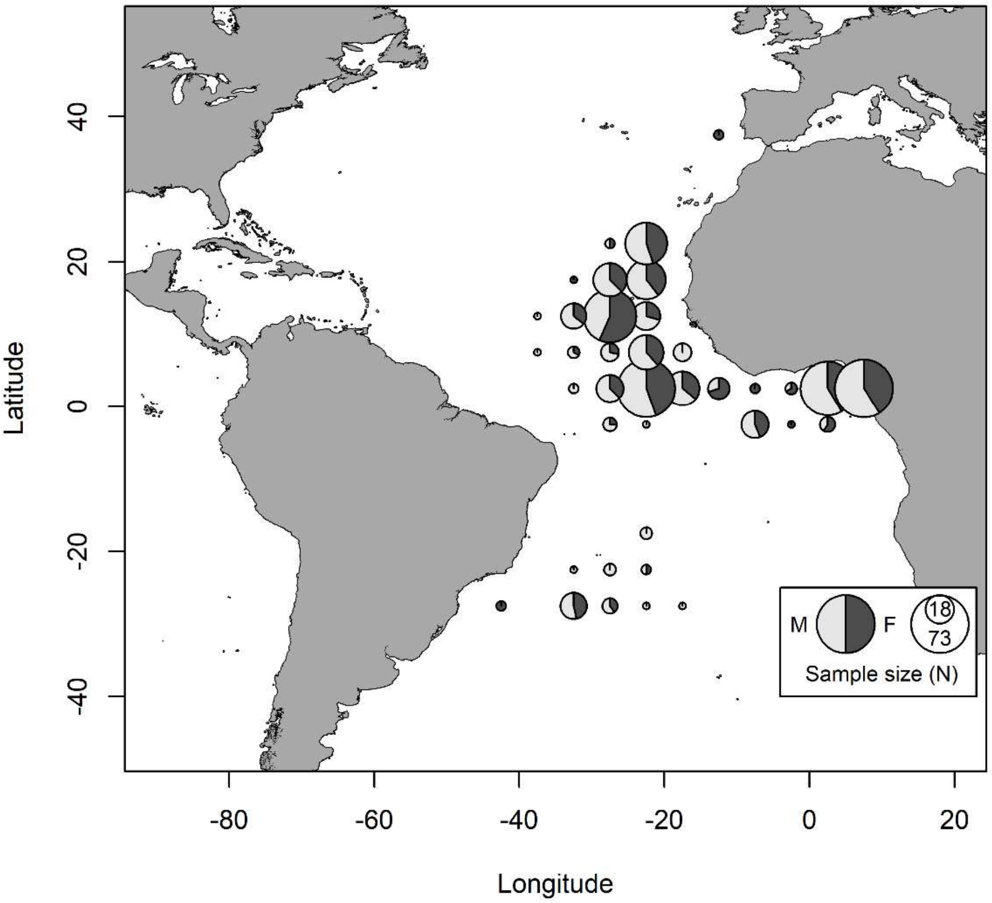

Latitude
40
20
0
-20
-40
Longitude
-80
-60
-40
-20
0
20
M
F
18
73
Sample size (N)

Figure 6

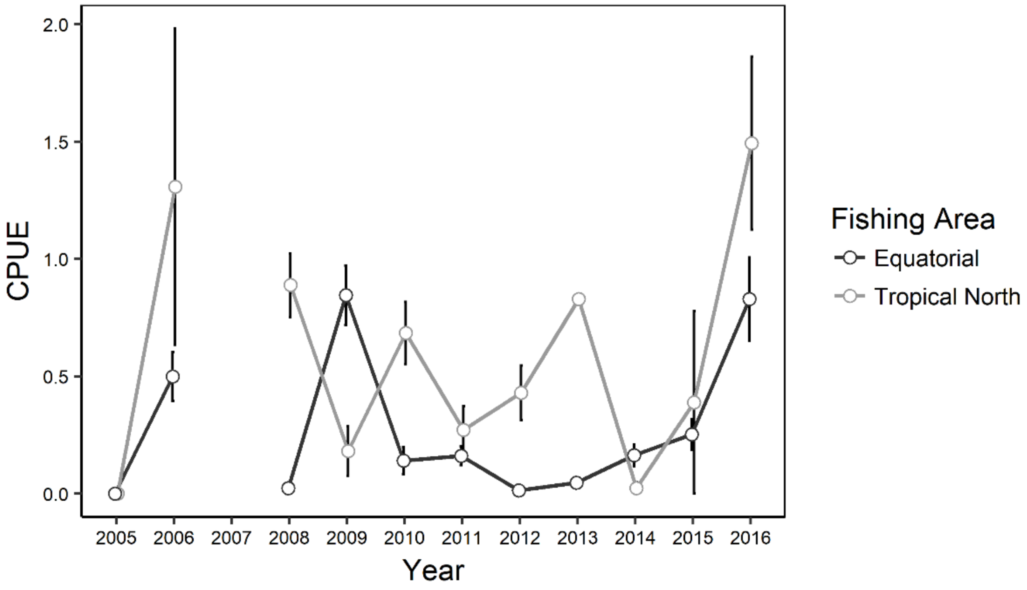
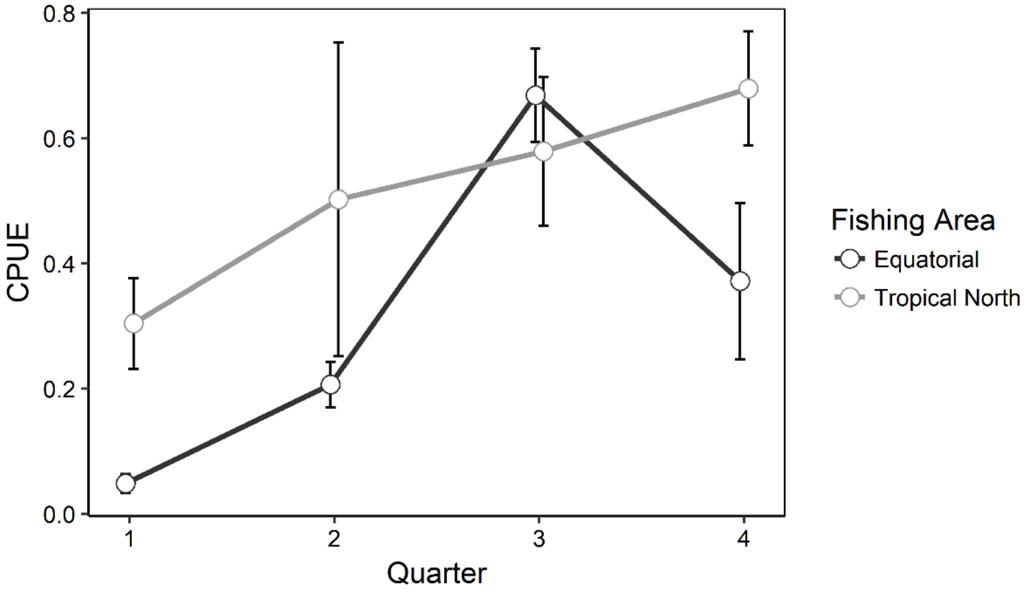

CPUE
2.0
1.5
1.0
0.5
0.0
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Year
Fishing Area
Equatorial
Tropical North

Figure 7



0.8
0.6
0.4
0.2
0.0
CPUE
1
2
3
4
Quarter
Fishing Area
Equatorial
Tropical North

Figure 8

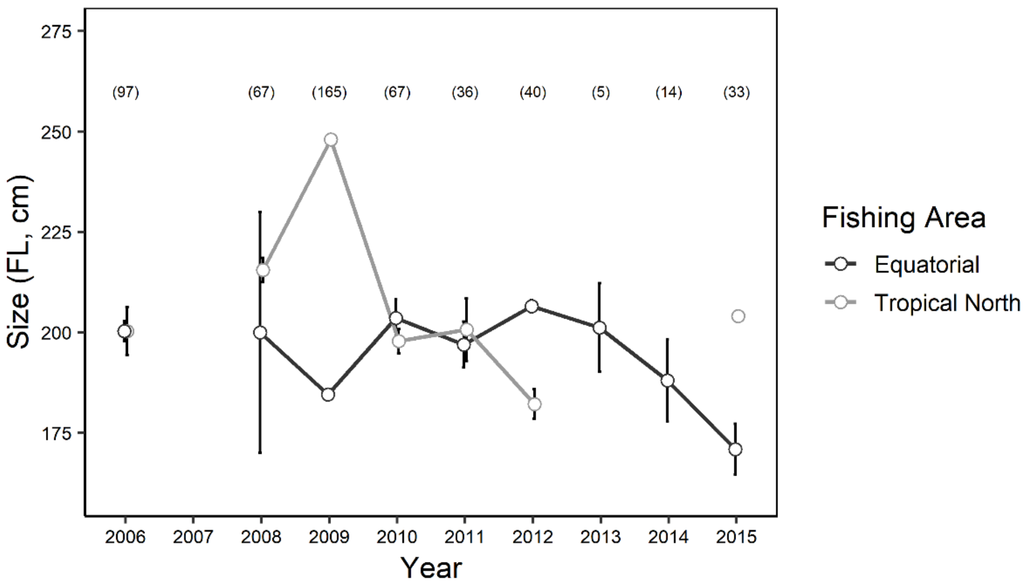

(97)
(67)
(165)
(67)
(36)
(40)
(5)
(14)
(33)
275
250
225
200
175
Size (FL, cm)
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year
Fishing Area
Equatorial
Tropical North

Figure 9

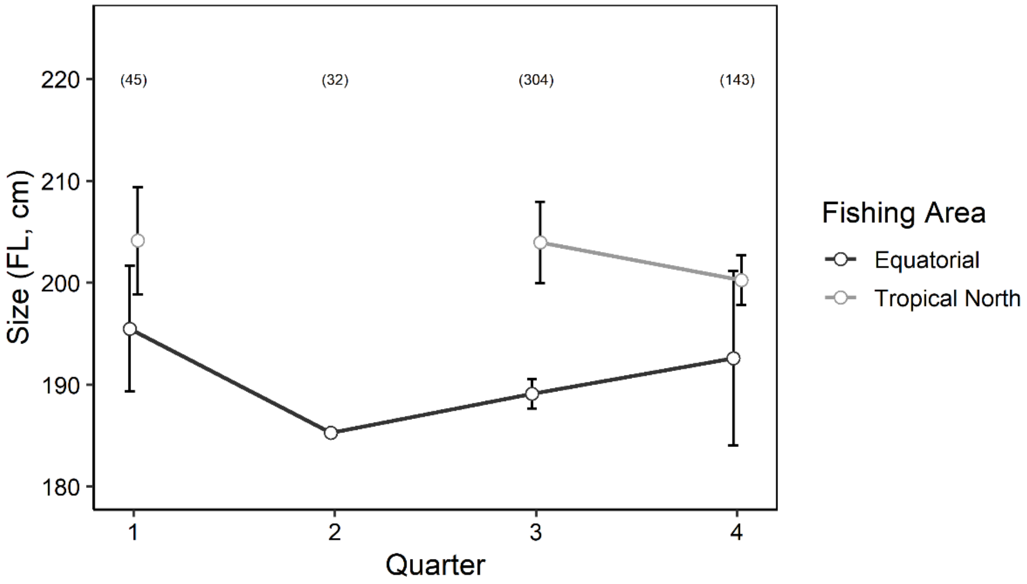
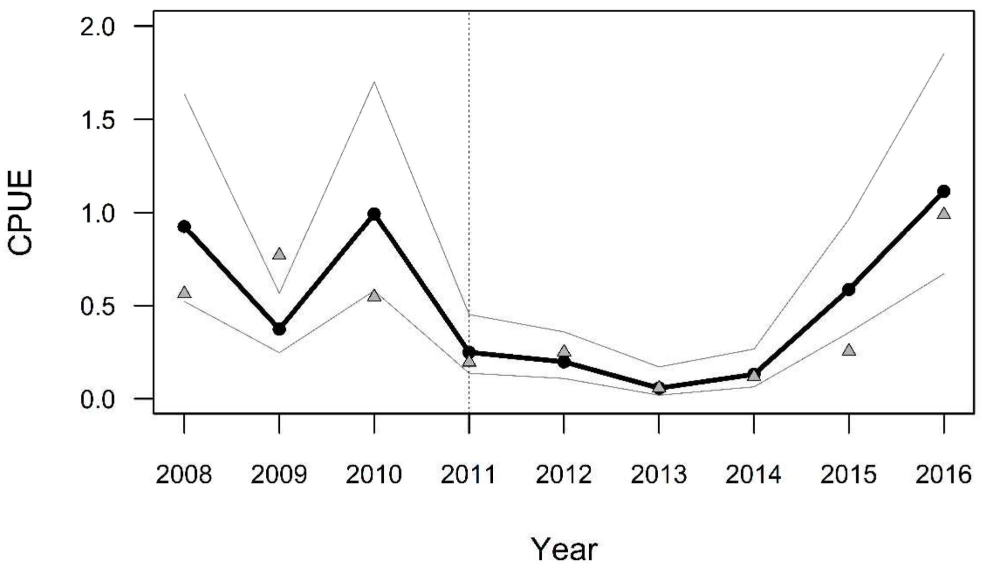

220
210
200
190
180
Size (FL, cm)
(45)
(32)
(304)
(143)
1
2
3
4
Quarter
Fishing Area
Equatorial
Tropical North

Figure 10


2.0
1.5
1.0
0.5
0.0
CPUE
2008
2009
2010
2011
2012
2013
2014
2015
2016
Year