DISTRIBUTION PATTERNS OF THE BLUE SHARK *Prionace glauca* IN THE ATLANTIC OCEAN, FROM OBSERVER DATA OF THE MAJOR FISHING FLEETS

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SUMMARY

The blue shark is the most captured shark in pelagic longline fisheries targeting tunas and swordfish. As part of an ongoing cooperative program for fisheries and biological data collection, information collected by fishery observers and scientific projects from several fishing nations in the Atlantic (EU.Spain, EU.Portugal, Uruguay, Taiwan, USA, Japan, Brazil, Venezuela and South Africa) were analyzed. Datasets include information on geographic location, size and sex. A total of 414,428 blue shark records collected between 1992 and 2014 were compiled, with the sizes ranging from 36 to 394 cm FL (fork length). Considerable variability was observed in the size distribution by region and season, with larger sizes tending to occur in equatorial and tropical regions and smaller sizes in higher latitudes. The expected distribution of juvenile and adult specimens also showed considerable variability, and the sex ratios varied between regions and size classes. The distributional patterns presented in this study provide a better understanding of different aspects of this species in the Atlantic that can help to promote more informed management and conservation measures.

KEYWORDS: Blue shark, catch-at-size, sex ratios, size composition, size distribution, spatial distribution, spatial models.

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1. Introduction

The blue shark, *Prionace glauca*, is one of the widest ranging of all sharks, found throughout tropical and temperate seas from latitudes of about 60°N to 50°S (Last and Stevens, 2009). It is a pelagic species mainly distributed from the sea surface to depths of about 350m, even though deeper dives of up to 1000m have been recorded (Campana, et al., 2011). The blue shark is an oceanic species capable of large scale migrations (Queiroz et al., 2005; Silva et al., 2010; Campana et al., 2011), but can also occasionally occur closer to inshore waters, especially in areas where the continental shelf is narrow (Last and Stevens, 2009).

Blue sharks can be captured by a variety of fishing gears, but most catches take place as bycatch in pelagic longlines targeting tunas and swordfish. In the Atlantic, the average reported blue shark catch in the last 5 years (2009-2013) was 63,368t, of the average total 685,686t catches (all species combined) that have been reported to ICCAT (*International Commission for the Conservation of Atlantic Tunas*) (ICCAT, 2014a). Blue shark is the most prevalent shark captured in pelagic longline fisheries (Mejuto, 1985; Castro et al., 2000; Mejuto et al., 2009), and in some cases blue shark catches can account for more than 50% of the total fish catch and 85-90% of the total elasmobranch catch (Coelho et al. 2012).

The main objective of this paper is to provide a contribution to the 2015 ICCAT blue shark stock assessment by analyzing detailed catch-at-size information from the major longline fleets that target tunas or swordfish in the Atlantic Ocean. The specific objectives are to 1) analyze the distribution and seasonal patterns of the blue shark catch-at-size in the Atlantic, 2) provide time series trends in the catch-at-size by region and fleet, 3) analyze the distribution of the sex ratios and 4) model the expected catch-at-size and proportion of juveniles/adults by region and season.

2. Materials and methods

2.1. Data collection

Blue shark records and data were taken by scientific observers and port samplers working on national data collection programs and scientific projects from IEO (*Instituto Español de Oceanografía*), IPMA (*Portuguese Institute for the Ocean and Atmosphere*), DINARA (*Dirección Nacional de Recursos Acuáticos*), Taiwan Fisheries Agency, NOAA/NMFS (*National Marine Fisheries Service*), NRIFSF (*National Research Institute of Far Seas Fisheries*), Brazil, Venezuela (*ICCAT's EPBR-Venezuelan Pelagic Longline Observer Program*) and South Africa. Data were available for 1993-2013 for EU.Spain, 1997-2013 for EU.Portugal, 1998-2012 for Uruguay, 2004-2013 for Taiwan, 1992-2014 for USA, 1997-2014 for Japan, 2004-2008 for Brazil, 1994-2013 for Venezuela and 2012-2014 for South Africa. The spatial effort distribution for those 9 fleets was expressed as the total number of hooks in 5ºx5º resolution grids using the ICCAT effort distribution (EffDIS) database (Palma and Gallego, 2010). Only the years for which blue shark data were available for each fleet were considered noting that the current ICCAT EffDIS database has data until 2009.

Data were collected across a wide geographical range. For analysis purposes, the two hemispheres were separated based at the 5ºN parallel, as recommended in the ICCAT Manual for shark species (ICCAT, 2006-2014). Furthermore, the study area was divided into eight major areas taking into consideration the ICCAT sampling areas for sharks (ICCAT, 2006-2014).

For captured specimens, data on specimen size, sex, capture location and date was recorded. The size measurement most often taken was the fork length (FL), but there were some exceptions as some of the national programs also record other measurements (e.g., precaudal length, total length, weight). In those cases, all sizes and weights were converted to FL using equations available at the national research institutes, specifically:

$DW = 0.0068 + LW*0.4167$ (IPMA, *unpubl. data*),
$LW = 0.0000015 + FL\text{^}3.2907$ (IPMA, *unpubl. data*),
$FL = -1.122 + TL*0.829$ (NRIFSF, *unpubl. data*),
$PCL = -2.505 + TL*0.762$ (NRIFSF, *unpubl. data*),

where DW = dressed weight (kg), LW = live weight (kg), PCL = pre-caudal length (cm), FL = fork length (cm) and TL = total length (cm).

2.2. Data analysis

Size data were tested for normality with Kolmogorov-Smirnov normality tests with the Lilliefors correction (Lilliefors, 1967), and for homogeneity of variances with Levene tests (Levene, 1960). Specimen sizes were compared between regions, sexes and quarters of the year using non-parametric *k*-sample permutation tests (Manly, 2007). The annual trends of the mean catch-at-size were plotted and analyzed by fleet and by region.

Sex ratios were calculated and compared between regions with contingency tables and Pearson's chi-squared tests. Sex ratios were also compared between the seasons of the year and size classes (categorized by the 20% percentiles of the data) taking into account the various regions, using Cochran-Mantel-Haenszel (CMH) chi-squared tests. This test allows detecting seasonality of size-related effects in the sex ratios conditional to each of the regions analyzed.

A Generalized Additive Model (GAM) with a gaussian error structure and identity link function was specified to predict the expected blue shark catch-at-size as a function of location (latitude and longitude), year and quarter. The linear predictor in this model was given by the smooth functions of latitude and longitude plus parametric components for the year and quarter factors. The smooth terms for the location covariates was estimated by thin plate regression splines (Wood, 2003). The significance of the model parameters was tested with likelihood ratio tests (LRT) comparing nested models, including the significance of the interaction between year and quarter. A residuals analysis was carried out to validate the models, and the goodness-of-fit was assessed with the Akaike Information Criteria (AIC; Akaike, 1973) and with the final deviance explained. The expected mean catch-at-sizes were mapped along the study area for each year/quarter combination.

A Generalized Linear Mixed Model (GLMM) with a binomial error distribution and logit link function was specified to determine the influence of each region and quarter on the proportion of juvenile specimens caught. The median sizes-at-maturity (FL) used to define juvenile and adult specimens were defined according to the ICCAT-Sharks Working Group report (ICCAT, 2014b) as follows: North Atlantic: females = 182.1 cm, males = 197.0 cm; South Atlantic: females = 173.8 cm, males = 175.5 cm. The random effects considered in this model were the year and fleet effects. The significance of the model parameters, including interactions, were tested LRT comparing nested models, and the significance of the random effects was given by their estimated variance. Model goodness-of-fit was assessed with the AIC. The discriminative capacity of the models was determined by the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) curves (Fawcett, 2006), with the calculation of the model sensitivity (capacity to correctly detect the event, in this case defined as the capture of juveniles) and model specificity (capacity to correctly exclude the non-events, in this case the capture of adults). The odds-ratios of the fixed effects with their respective 95% confidence intervals (CI) were calculated and used for model interpretation. The area BIL92 and quarter 1 were used as the baseline parameters, and the odds-ratios calculated comparatively for the other regions and quarters of the year, taking into account their interaction effects.

The analysis for this paper was carried out using the R language for statistical computing version 3.0.1. (R Core Team, 2013). Additional libraries that were used included "aods3" (Lesnoff and Lancelot, 2013), "boot" (Davison and Hinkley, 1997; Canty and Ripley, 2013), "car" (Fox and Weisberg, 2011), "classInt" (Bivand, 2013), "Epi" (Carstensen et al., 2013), "ggplot2" (Wickham, 2009), "gmodels" (Warnes et al., 2013), "lme4" (Bates et al., 2013), "maps" (Becker et al., 2013), "mapplots" (Gerritsen, 2013), "maptools" (Bivand and Lewin-Koh, 2013), "mgcv" (Wood, 2006, 2011), "nortest" (Gross and Ligges, 2012), "perm" (Fay and Shaw, 2010), "plyr" (Wickham, 2011), "RColorBrewer" (Neuwirth, 2011), "rgdal" (Bivand, et al., 2013), "scales" (Wickham, 2012) and "shapefiles" (Stabler, 2013).

3. Results

3.1. Spatial distribution in the catch-at-size

A total of 414,428 blue sharks were recorded and considered within the scope of this study, specifically 99,053 from Spain, 87,490 from Portugal, 69,157 from Uruguay, 59,107 from Taiwan, 58,276 from USA, 33,206 from Japan, 6,242 from Brazil; 1,376 from Venezuela and 521 from South Africa. The specimens ranged in size from 36 to 394 cm FL (both males and females), covering most of the known size range of the species. Considering the ICCAT geographical and sampling areas for sharks in the Atlantic, 110,221 specimens were sampled in the

NE region (78,860 in sampling area BIL94B and 31,361 in area BIL94C), 85,630 specimens were sampled in the NW (90 in area BIL91; 27,129 in area BIL92; 1,063 in area BIL93 and 57,348 in area BIL94A), 110,424 specimens were sampled in the SW (area BIL96) and 108,153 in the SE (area BIL97) (**Figure 1**).

The spatial distribution of the effort of these fleets during the years for which data were available also covered a wide geographical area over the entire Atlantic Ocean. However, higher fishing effort was reported along the temperate, tropical and equatorial eastern Atlantic, and also in some areas of the northwest Atlantic (**Figure 2**). The effort of those fleets for those years accounted for 73.9% of the total estimated longline effort by all fleets in the Atlantic for the same period.

Size data were not normally distributed (Lilliefors test: D = 0.0371, p-value < 0.001) and the variances were heterogeneous between regions (Levene test: F = 2077.6, df = 7, p-value < 0.001) and sexes (Levene test: F = 222.44, df = 1, p-value < 0.001). Using univariate non-parametric statistical tests revealed that sizes were significantly different among regions (Permutation test: chi-squared = 59335.5, df = 7, p-value < 0.001) and between sexes (Permutation test: chi-squared = 463.7, df = 1, p-value < 0.001).

Considerable variability was observed in the size distribution of males and females in the Atlantic regions. In some areas such as the SW and SE Atlantic (areas BIL96 and BIL97) the size distribution was mostly unimodal, while in the NE Atlantic (areas 94B and 94C) there was some evidence of bimodal distributions (**Figure 3**). The larger blue sharks size distribution were observed in areas of the NW Atlantic (BIL93) and in the SE Atlantic mainly (BIL97). In the other areas the mean blue shark catch sizes tended to be smaller, particularly in the central area of the NW Atlantic (BIL94A) and in the SW Atlantic (BIL96) (**Figure 4**). Those general trends were common for both males and females, but in some areas, such as BIL94C there were large differences, with the female size distribution much larger than the males (**Figure 4**).

3.2. Seasonal variability in the catch-at-size

Seasonality and sex seems to influence the size of captured blue sharks. In some regions the sizes tended to be larger than in others, but in most cases similar trends were observed for males and females along the quarters of the year. This was most evident in region BIL96 and BIL92 where both males and female sizes tended to decrease along the quarters of the year, with the males tending to be larger than the females (**Figure 5**). However, there were some exceptions in some of the regions, such as in region BIL93, where the males were much larger than the females in quarters 1 and 4, and the females were larger in quarter 2 (**Figure 5**). The variances of the catch at size data were heterogeneous between quarters (Levene test: F = 256.3, df = 3, p-value < 0.001). Univariate non-parametric statistical tests revealed that sizes were significantly different comparing quarters in each individual region (Permutation tests: p-value < 0.001 on all cases), except for BIL91 (Permutation test: chi-square = 7.33, df = 3, p-value = 0.062) probably due to the low sample size in that region.

3.3. Annual trends in the catch-at-size

The time series of the catch at size distribution was relatively stable for some fleets (e.g. Portuguese, Spanish, Japanese and US) and considerably more variable for others (**Figure 6**). For the Uruguayan and Taiwanese fleets a decreasing trend was noticeable along the series, while in the Venezuelan fleet there was a period with larger sizes in the middle of the series and smaller sizes in the initial and later years (**Figure 6**). There were also differences in catch at size among regions, with some regions showing relatively more stable trends than others. Some of the areas with more stable time series were regions BIL92 and BIL97, while in areas such as BIL93, BIL94A and BIL94C there was higher variability (**Figure 7**).

3.4. Sex ratios

Of the overall blue sharks with sex recorded, 154,523 (46.2%) were females and 179,784 (53.8%) were males. There was some evidence of variability in the sex ratios with more males recorded off southern Brazil (around 30-40ºS and over a wide longitudinal range), in tropical waters off western central Africa, and in the NW Atlantic off the US coast (**Figure 8**). In contrast, there was a tendency for the presence of more females in the temperate NE Atlantic, particularly evident in latitudes higher than 50ºN, in tropical waters around the Cape Verde archipelago, and in the temperate SW Atlantic in latitudes south of 40ºS (**Figure 8**).

In some areas of the Atlantic there were noticeable changes in the sex ratios along the quarters of the year. In the temperate NE Atlantic closer to the Azores archipelago and in northern latitudes there were more females in quarters 4 and 1 and a tendency for more males in quarters 2 and 3 (**Figure 9**). In tropical NE waters closer to the Cape Verde archipelago there were more females throughout the year except in quarter 2 when many more males were recorded (**Figure 9**). In the central South Atlantic there seemed to be more males, particularly in quarters 1 and 2, while in the SW temperate Atlantic there were more females in quarter 3 (**Figure 9**).

There were significant differences in the overall sex ratios among the major ICCAT sampling areas (prop. test: chi-squared: 3917.6, df = 7, p-value < 0.001). The proportion of females was higher in regions of the NE and central-west Atlantic, particularly in BIL93, BIL94B and BIL94C, while the proportion of males was higher in the remaining regions, particularly in the NW (BIL92) and South Atlantic (BIL96 and BIL97) (**Figure 10**).

There were also significant differences in sex ratios among seasons, even when compared conditionally within each of the different ICCAT regions (CMH test: chi-squared = 1981.7, df = 3, p-value < 0.001). In the NE and north central Atlantic (BIL94A, BIL94B and BIL94C) the trends were very similar, with a higher proportion of males in Quarter 2 and relatively more females in the other quarters (**Figure 11**). In contrasts, in the NW Atlantic, particularly in areas BIL91 and BIL93 more males were recorded in Quarter 1, while in area BIL92 the ratios were very similar throughout the year (**Figure 11**). In the SW Atlantic the trend was more similar to the NW Atlantic (even though the quarters correspond to opposite seasons), while in the SE Atlantic the sex ratios were very constant throughout the year (**Figure 11**).

Significant differences were also detected in the sex ratios among sizes tested conditionally within the different regions (CMH test: chi-squared =5701.8, df = 4, p-value < 0.001). In regions such as BIL94A in the North Atlantic and BIL96 in the SW Atlantic there was a gradual change from more females in the smaller sizes to a male dominance in the larger sizes (**Figure 12**). In some regions such as BIL93 and BIL94C the sex ratios were more variable across sizes, while in BIL94B the sex ratios were very constant independently of specimen size (**Figure 12**). This means that the differences previously observed in the overall sex ratios among regions could be caused by the size segregation of individuals in those regions along the quarters of the year.

3.5. Modelling the catch at size

There was considerable variability in the expected catch-at-size in the Atlantic when taking into consideration the catch locations, year and quarter of the year. The larger mean blue shark sizes were predicted to occur mainly along the equatorial and tropical regions particularly in the central eastern Atlantic and in the Gulf of Mexico. By contrast, the smaller specimens were predicted to occur mainly in higher latitudes both in the north and southern hemispheres, especially in the NE and SW regions of the Atlantic (**Figure 13**). The final estimated GAM model considered the non-parametric smooth terms for location (latitude and longitude) and the parametric terms year and quarter used as fixed factors (quarter: F=28.5; df=3; p-value < 0.001; year: F=796.6; df=22; p-value < 0.001). The total deviance explained by this model was 43.1%, and in terms of goodness of fit the AIC decreased from 4104057 to 4086709 when adding both the quarter and year effects to the smooth location parameters, meaning that the model was better fitted when using all the variables considered.

3.6. Expected distribution of juveniles and adults

Considerable variability was observed in the distribution of juvenile and adult specimens when considering the region and quarters of the year, and in general the trends were similar for both sexes (**Figure 14**). Regions such as BIL94A tended to have a much higher proportion of juveniles, while in BIL97 there were many more adults and this pattern was similar for both sexes. In terms of seasonality, the region with the highest seasonal variability was BIL94C with a very high proportion of juveniles observed in quarter 2 and a much higher proportion of adults in quarter 3 (**Figure 14**).

The estimated logistic-binomial GLMM considered the fixed factors area (F=2916.7; df=6; p-value < 0.001), quarter (F=525.6, df=3, p-value < 0.001) and the interaction between quarter and area (LRT for nested models: chi-squared = 9478.3, df=18; p-value < 0.001). The two random variables used (year and fleet) showed a variance of 0.561 for the year effect (23 groups) and 1.188 for the fleet effect (9 groups), meaning that the variability associated with the fleets was higher than the yearly variability. In terms of model goodness-of-fit, the AIC value decreased from 343246 to 333997 when adding the interaction, meaning that the model using the area:quarter interaction was better fitted. This final model had an AUC of 0.753 (considered good), with a sensitivity of 80.6% and a specificity of 57.4%.

Compared to the baseline combination (BIL92 and quarter 1), the odds of capturing juveniles increased in some area-season combinations, whereas decreased in others. Specifically, the odds-ratios of capturing more juvenile specimens tended to increase in the central north and NE Atlantic, especially in areas BIL94A, BIL94B, BIL94C during quarters 1 and 2, and tended to increase less or even decrease in the NW and South Atlantic (BIL92, BIL96 and BIL97) (**Figure 15**).One particular area that showed very large seasonal differences was BIL94C, which had very high odds-ratios of capturing juveniles during quarters 1, 2 and 4 compared to quarter 3 (**Figure 15**).

4. Discussion

This work provides the most comprehensive study on blue shark catch at size distribution with data from fishery observer programs ever carried out in the Atlantic Ocean, and is an important contribution to the study of the spatial and seasonal dynamics of this species in the Atlantic. Significant differences were found in the length-frequency distributions, sex ratios and proportions of juvenile and adult specimens in the several regions of the Atlantic examined.

There seems to be a clear latitudinal distribution of the blue shark sizes in the Atlantic Ocean with the larger specimens tending to occur along the equatorial and tropical regions, and the smaller sizes occurring mainly towards higher latitudes both in the North and Southern hemispheres. There was also a longitudinal gradient as the larger specimens occurred mainly in the NW and SE tropical regions, while in the NE and SW the sizes tended to be smaller. The reasons for these differences might be related with migratory and habitat segregation patterns by growth stages between regions and seasons of the year, with the larger specimens preferring equatorial and tropical waters and the smaller specimens preferring colder water. This is opposite from the patterns found for other pelagic shark species, such as for example the bigeye thresher where the smaller and younger sharks tended to concentrate predominantly in the tropical regions, while the larger adults seemed to prefer temperate areas of the northern and southern Atlantic (Fernandez-Carvalho et al., 2014).

It is important to note that the data used in our study comes from several different fleets, with different fishing *métiers* that target different species, and as such the size ranges and abundance reported by each fleet for each region are also affected by area availability and fleet selectivity. With regards to the spatial distribution of the data, and while the observations reported reflect in part the species spatial dynamics, there is also some influence from the sampling effort of each fleet, and therefore the reported data may not be entirely representative of the prevalence of the species at each location. Additionally, some of the variability observed in the fleet time series analysis may be explained by lower sample sizes in some years.

This study provides a general overview of the size distribution at a wide Atlantic scale, but one possible limitation is the fact that the analysis and the models created are focusing mainly on the major spatial effects over the entire Atlantic area. There are probably finer scale effects and local variability patterns taking place that are not likely to be captured in such large scale models and analyses. Therefore, this study is important as a general overview and provides the general trends in the Atlantic, but it is also important to continue more detailed and local analysis for specific regions of the Atlantic.

Another main item of discussion resulting from this work is the definitions of the ICCAT sampling areas in the Atlantic. In this work we opted to used the ICCAT sampling areas for sharks (areas BIL in the Atlantic), but those do not seem the most adequate for such analysis, as they include very large areas with wide latitudinal gradients, from equatorial to tropical and temperate regions. As such, those areas should be further divided particularly with regards to the latitudes, in order to have more homogeneous areas. This seems to be corroborated by the observed blue shark size distribution, as the major changes in sizes are observed in terms of the latitudinal gradients.

The distributional patterns presented in this study provide a better understanding of different aspects of this species in the Atlantic that can be used in future stock assessments of the species, and help managers adopt more informed and efficient conservation measures.

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Figures

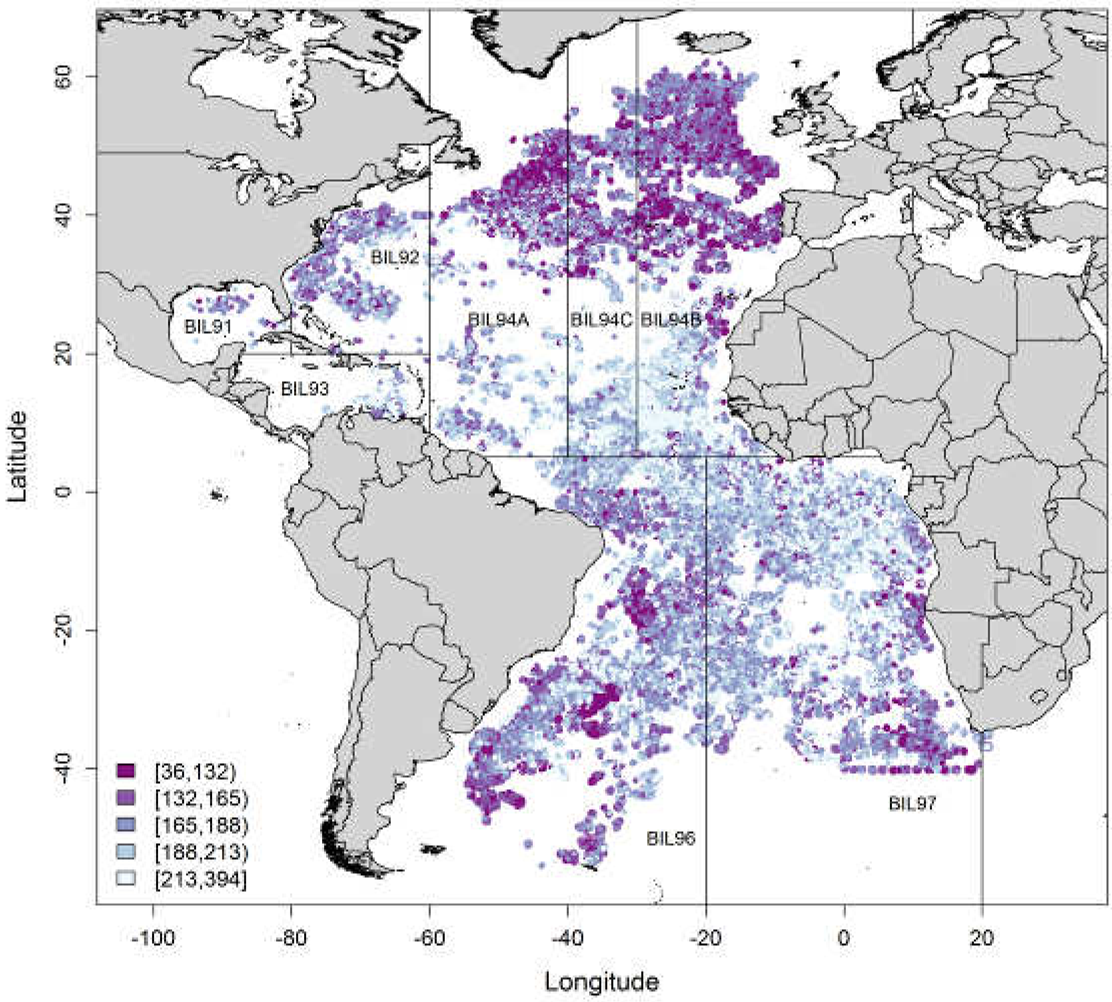

Figure 1. Location and catch-at-size (FL, cm) of the blue shark (*Prionace glauca*) recorded for this study in the Atlantic Ocean. The color scale of the dots represents specimen sizes, with darker colors representing smaller specimens and lighter colors larger specimens. The categorization of size classes for the map was carried out using the 0.2 quantiles of the data. The ICCAT sampling areas for sharks are identified (black lines). The values in parentheses in the legend represent the lower and upper limit of each 0.2 quantile.

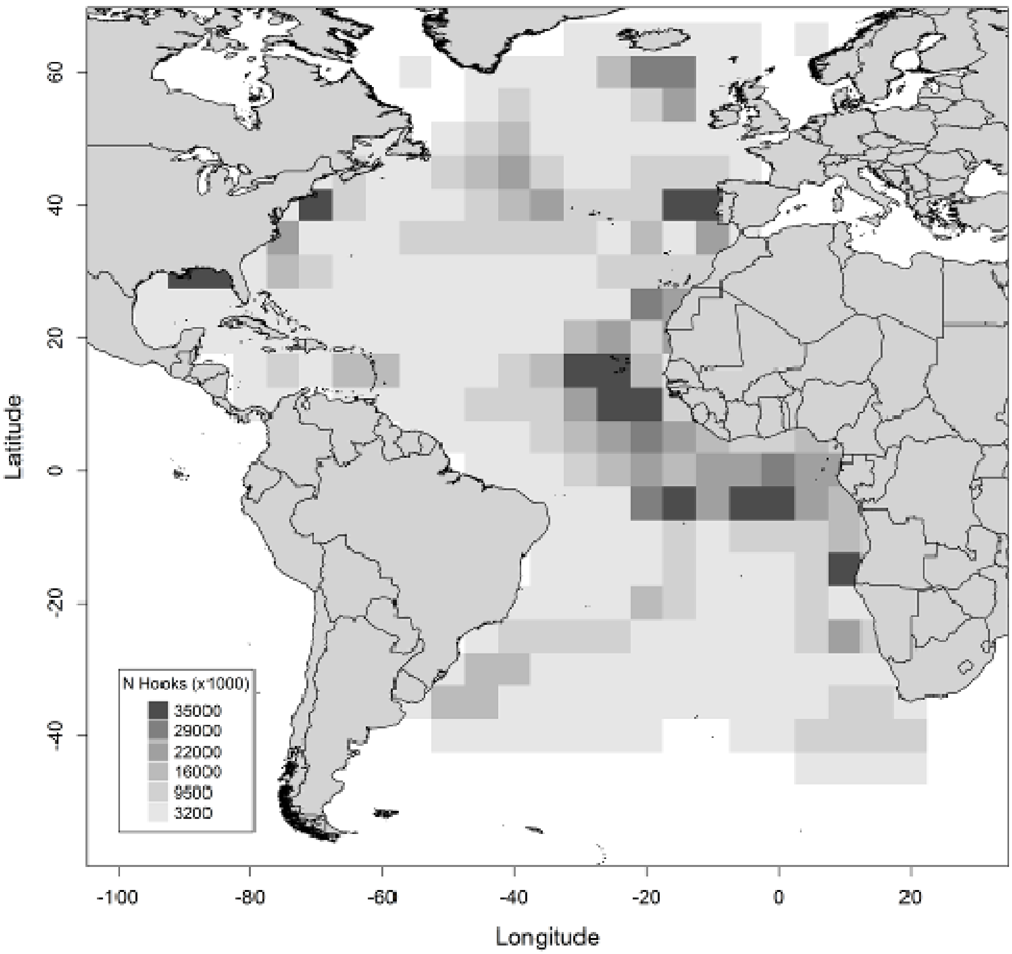

Figure 2. Effort distribution (number of hooks) in 5*5 degrees estimated from the ICCAT effort distribution (EffDIS) database (Palma and Gallego, 2010). Data is presented for the longline fleets from Brazil (2004-2008), EU.Spain (1993-2009), EU.Portugal (1997-2009), Japan (1997-2009), Taiwan (2004-2009), Uruguay (1998-2009), US (1992-2009) and Venezuela (1994-2009). The values in the legend refer to the upper limits in each effort class.

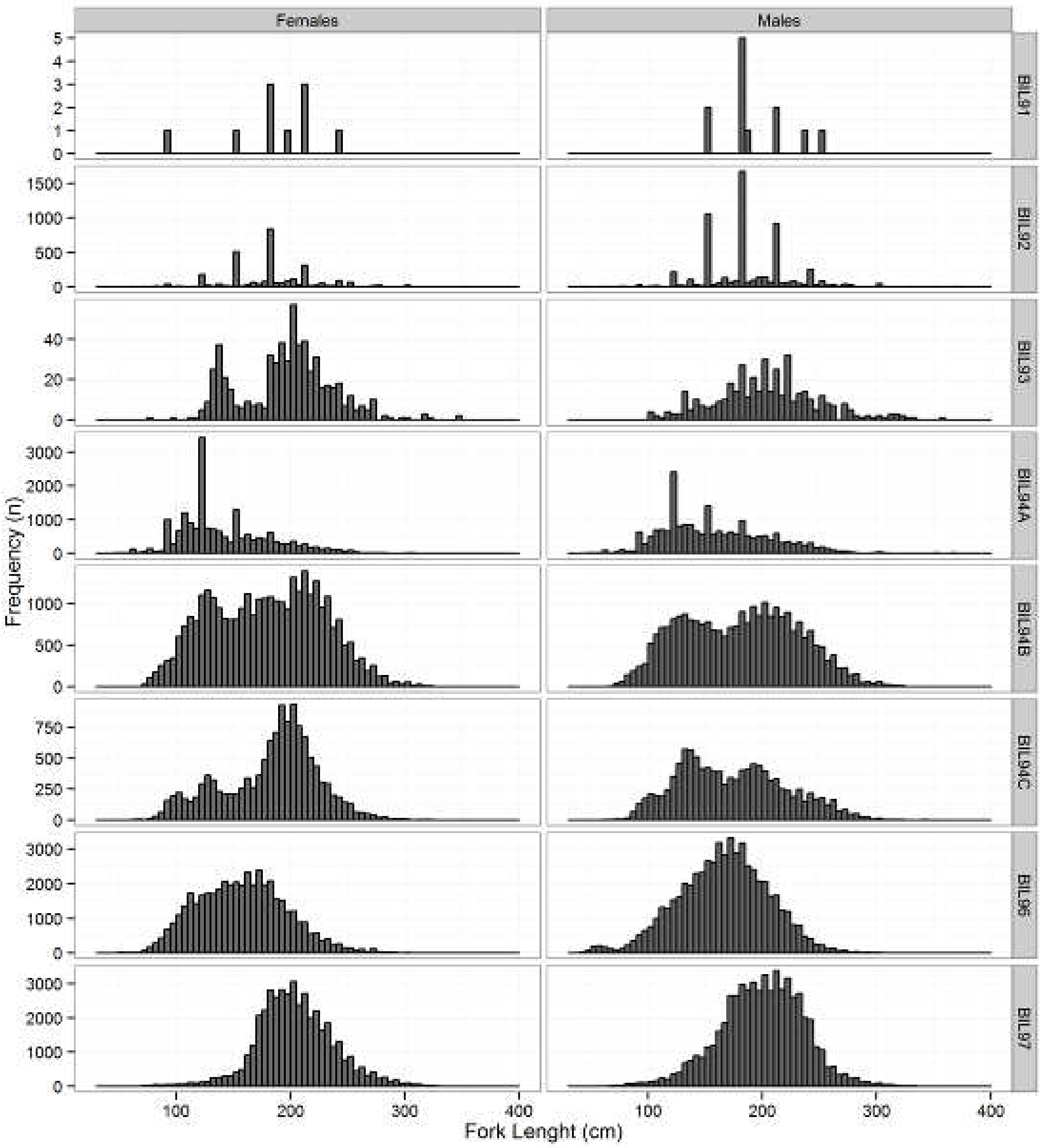

Figure 3. Size-frequency distributions of male and female blue shark (*Prionace glauca*) caught in the ICCAT sampling regions of the Atlantic Ocean.

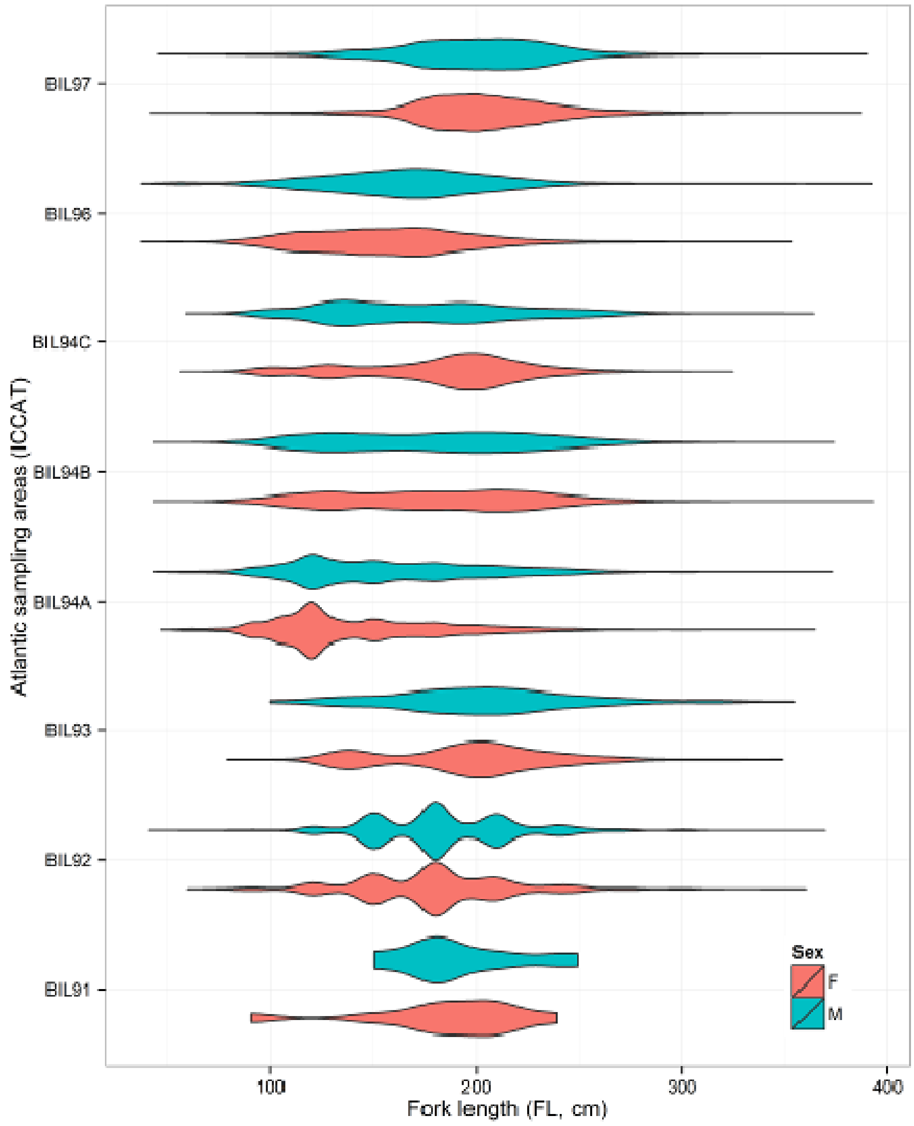

Figure 4. Overall size distribution (violin plots) of male and female blue shark (*Prionace glauca*) caught in the ICCAT sampling regions of the Atlantic Ocean during the period 1992-2014.

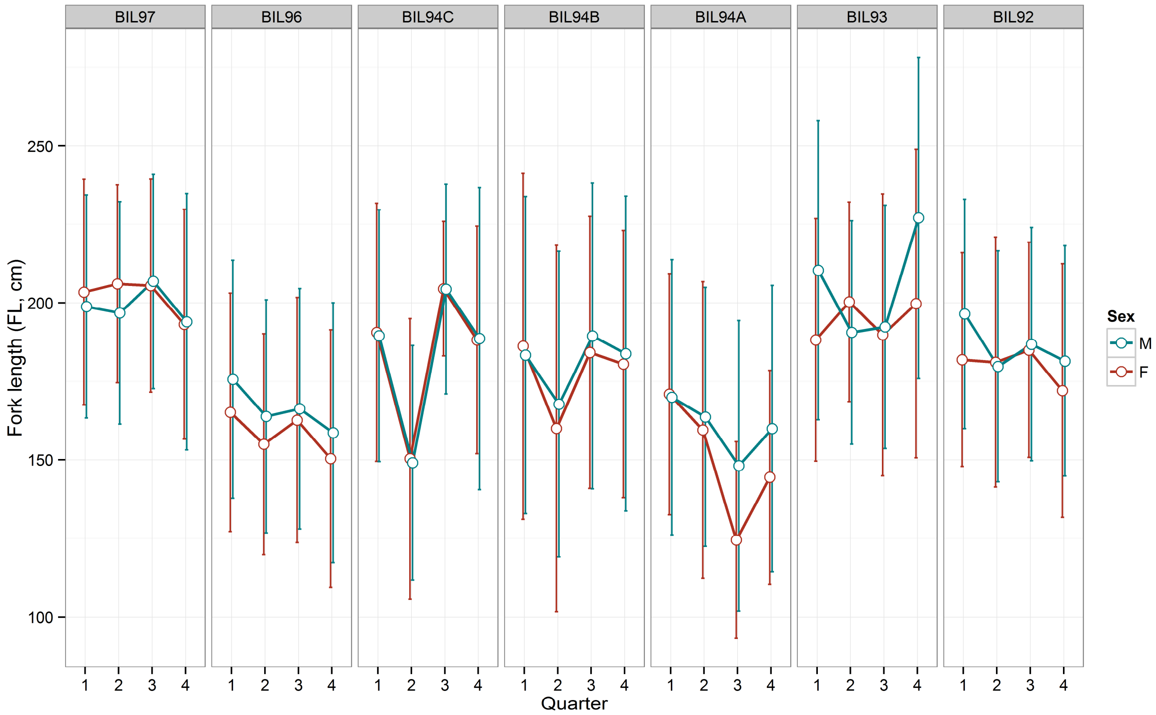

Figure 5. Mean size of male and female blue shark (*Prionace glauca*) caught in the ICCAT sampling regions of the Atlantic Ocean by quarter of the year, during the period 1992-2014. The error bars are ± 1 standard deviation.

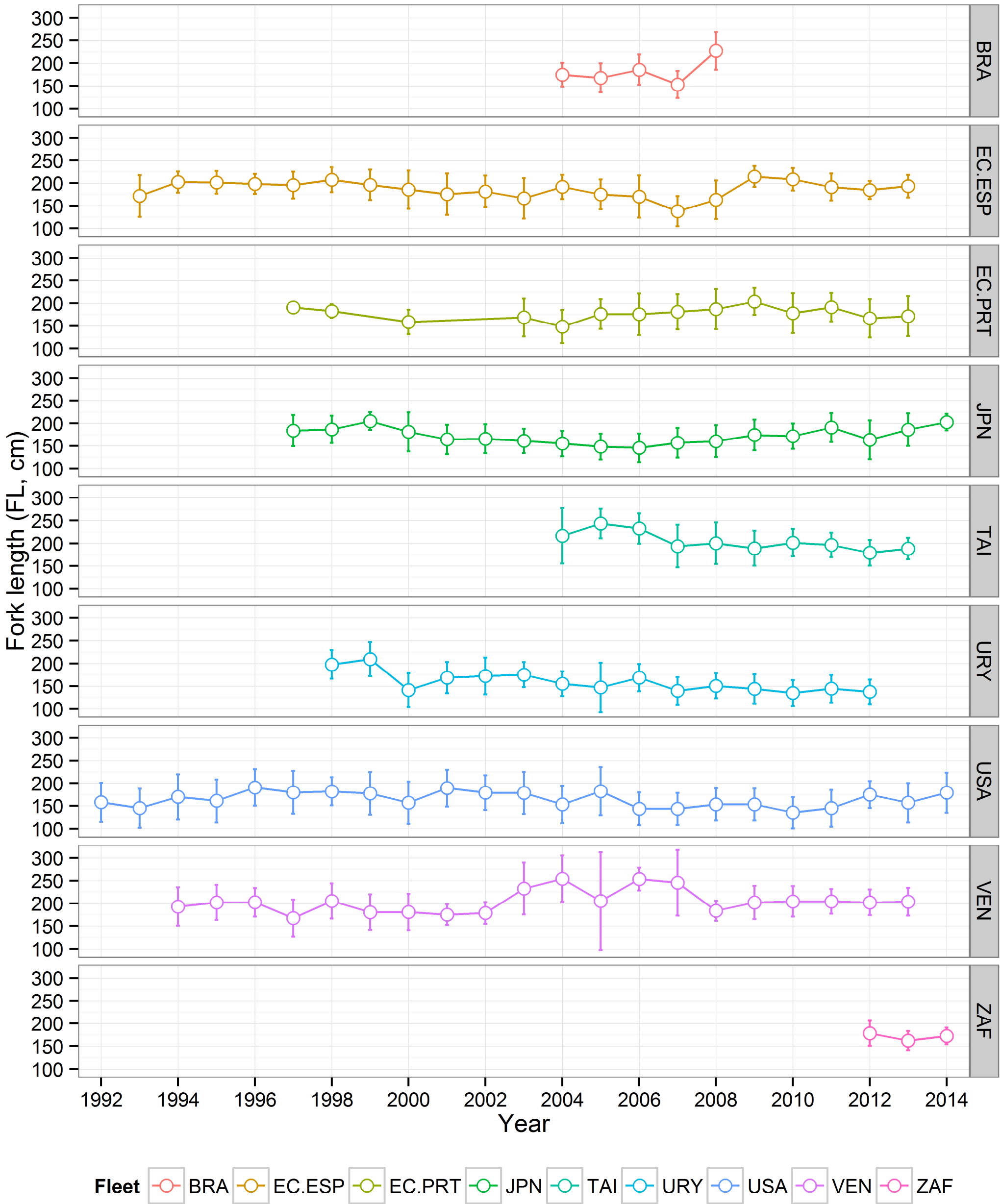

Figure 6. Mean sizes of blue shark (*Prionace glauca*) caught by the different fishing fleets in the Atlantic, during the period 1992-2014. The error bars are ± 1 standard deviation.

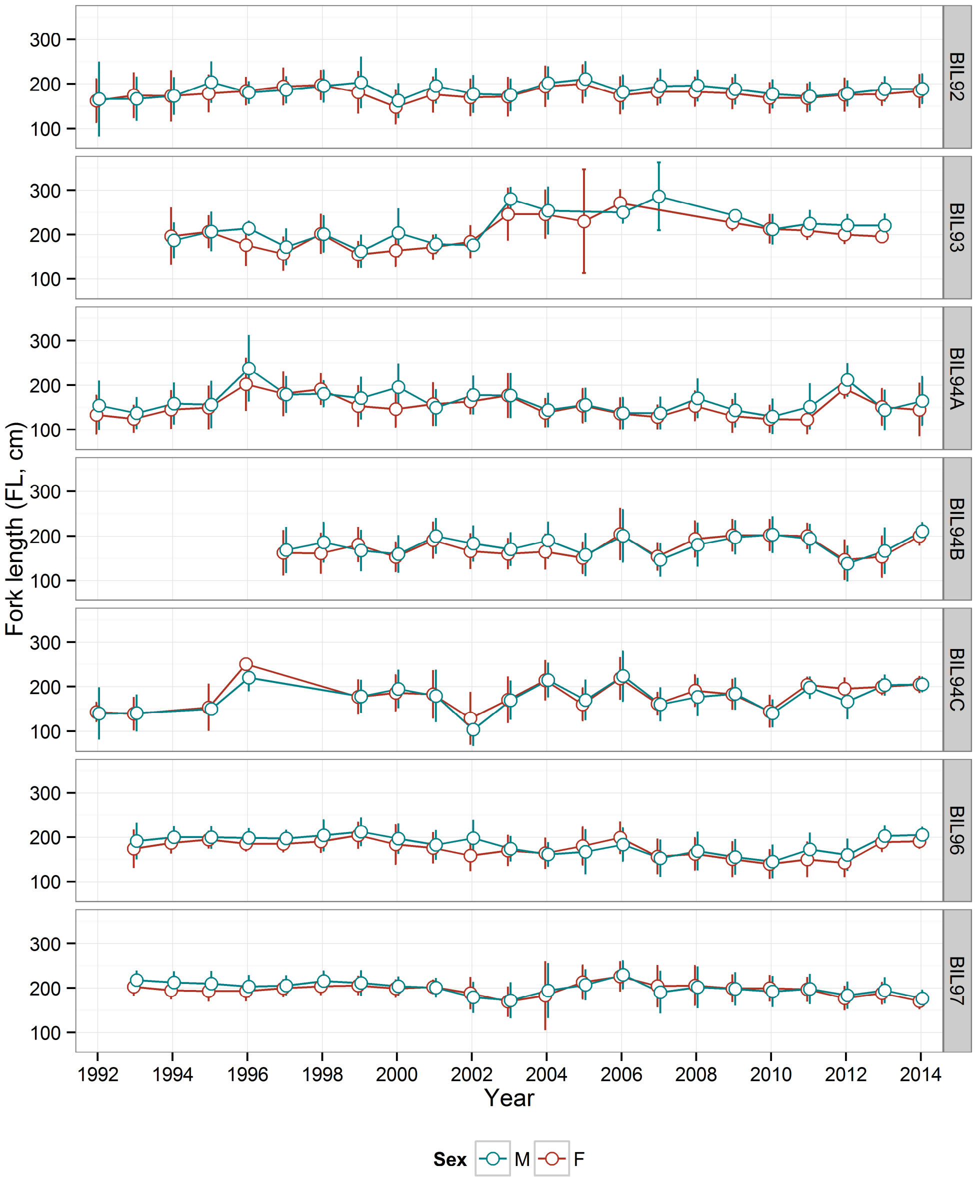

Figure 7. Mean size of blue shark (*Prionace glauca*) by sex caught in the different ICCAT sampling regions of the Atlantic Ocean, during the period 1992-2014. Region BIL91 was excluded from the analysis due to the low sample size. The error bars are ± 1 standard deviation.

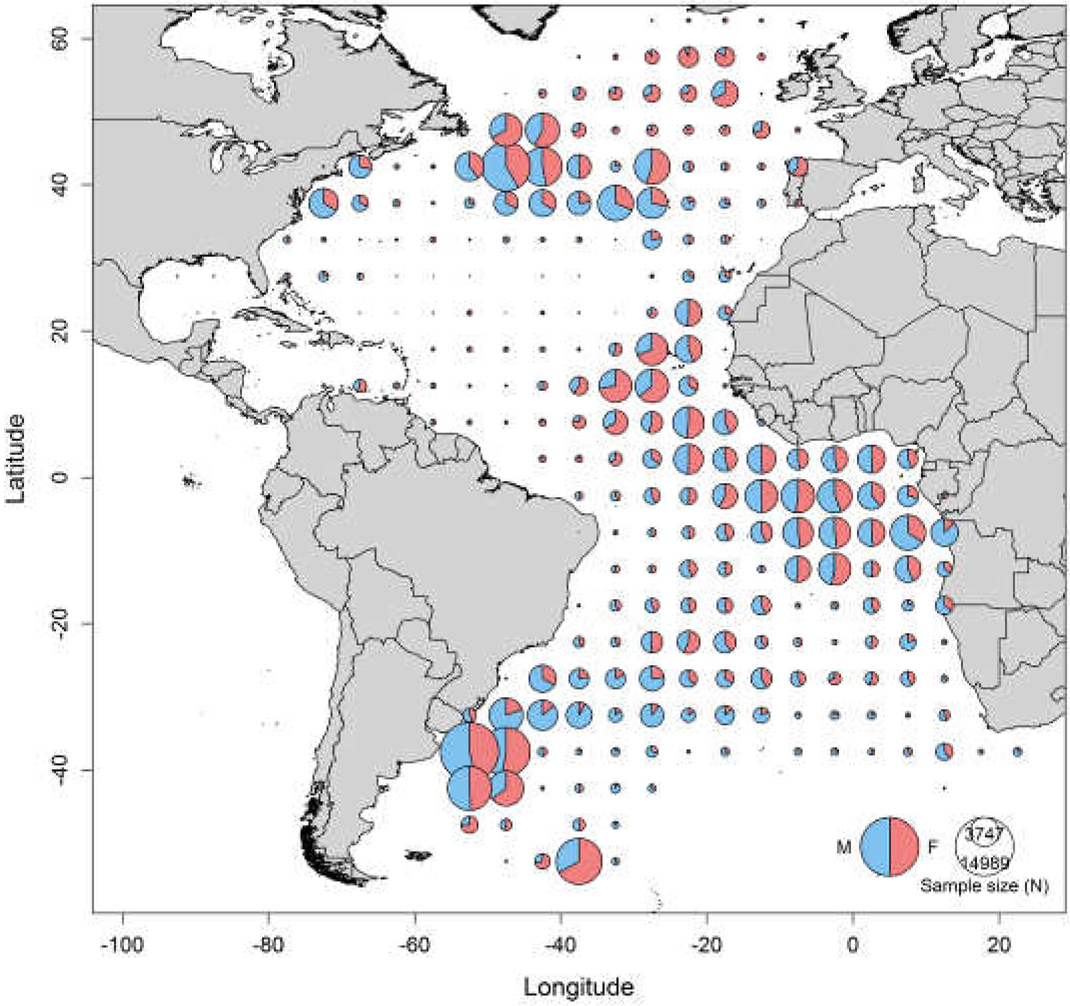

Figure 8. Blue shark (*Prionace glauca*) sex ratios recorded in 5ºx5º squares during this study, observed during the period 1992-2014. The circle sizes are proportional to the sample size (N) in each square.

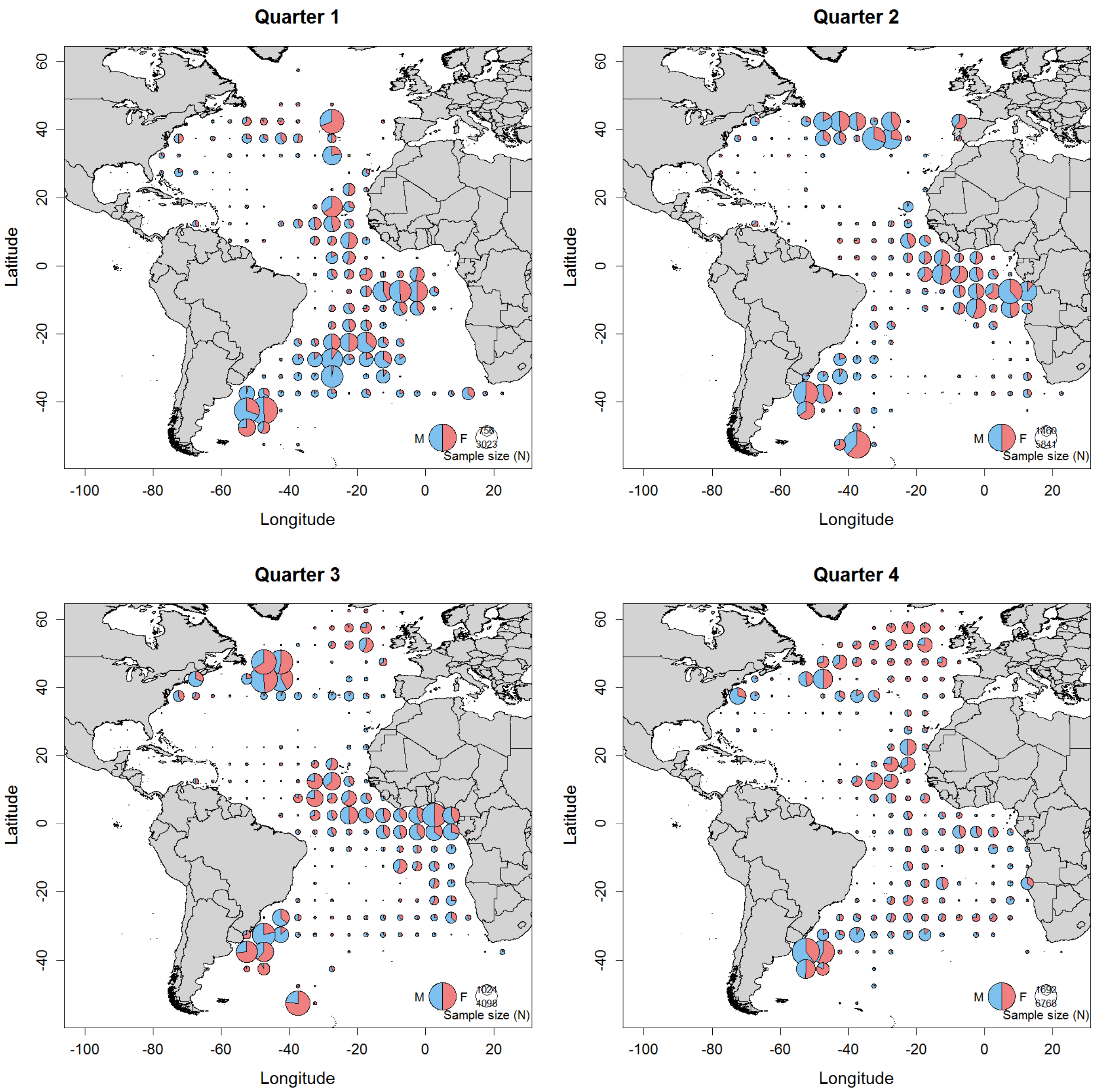

Figure 9. Blue shark (*Prionace glauca*) sex ratios recorded in 5ºx5º squares during this study in each quarter of the year, observed during the period 1992-2014. The circle sizes are proportional to the sample size (N) in each 5ºx5 square and in each quarter.

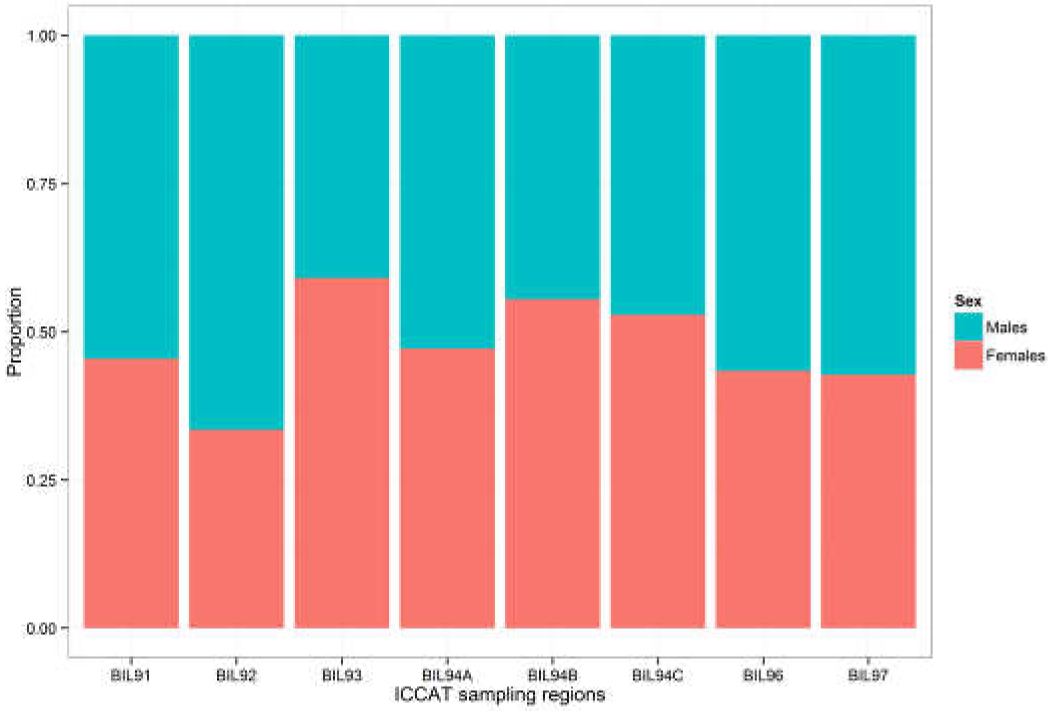

Figure 10. Sex ratios of blue shark (*Prionace glauca*, all sizes and seasons combined) in the ICCAT sampling regions of the Atlantic Ocean, during the period 1992-2014.

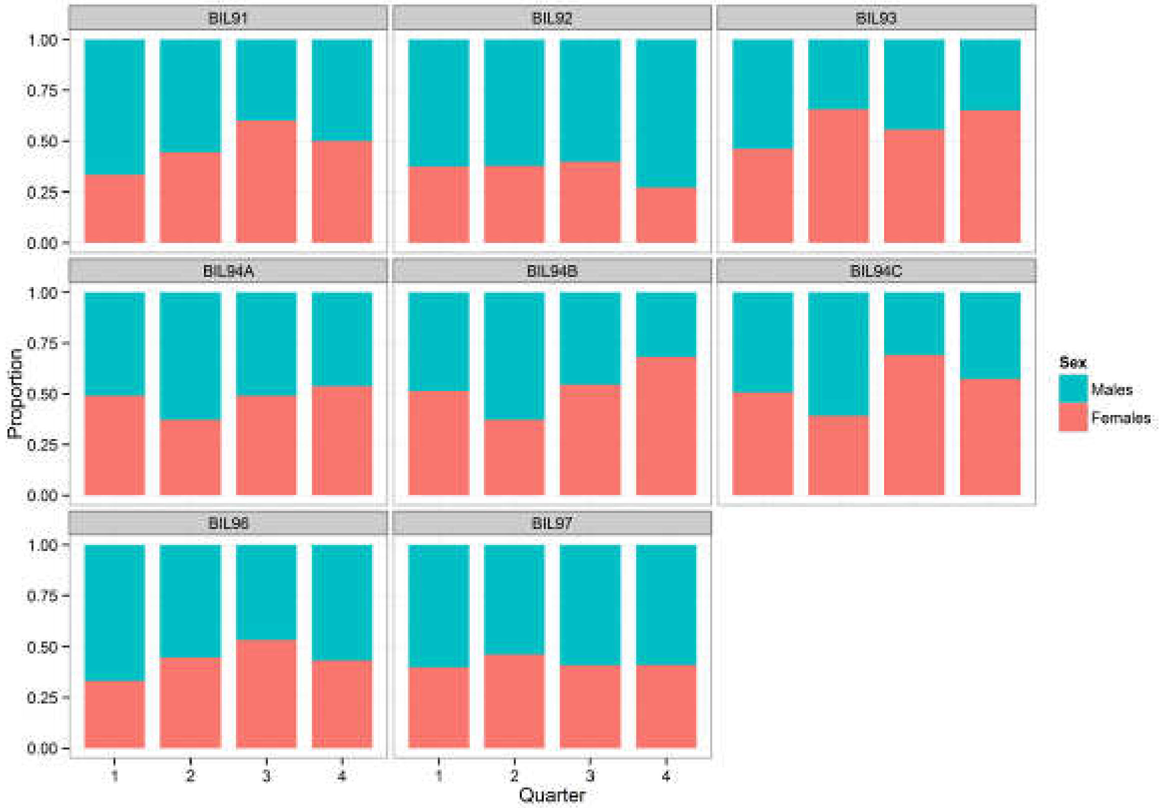

Figure 11. Sex ratios of blue shark (*Prionace glauca*, all sizes combined) per quarter of the year, in the ICCAT sampling regions of the Atlantic Ocean, during the period 1992-2014.

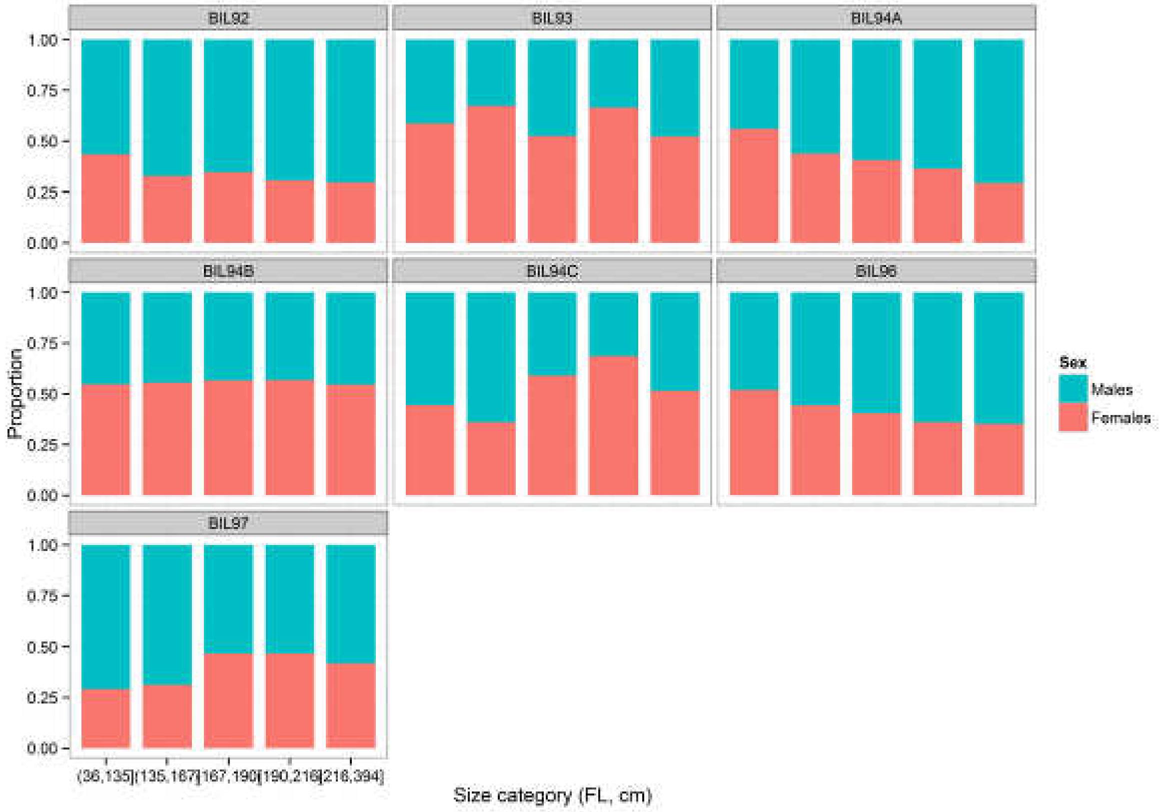

Figure 12. Sex ratios of blue shark (*Prionace glauca*, all sizes combined) per size class, in the ICCAT sampling regions of the Atlantic Ocean, during the period 1992-2014. The categorization of the size classes was carried out using the 20% percentiles of the size data.

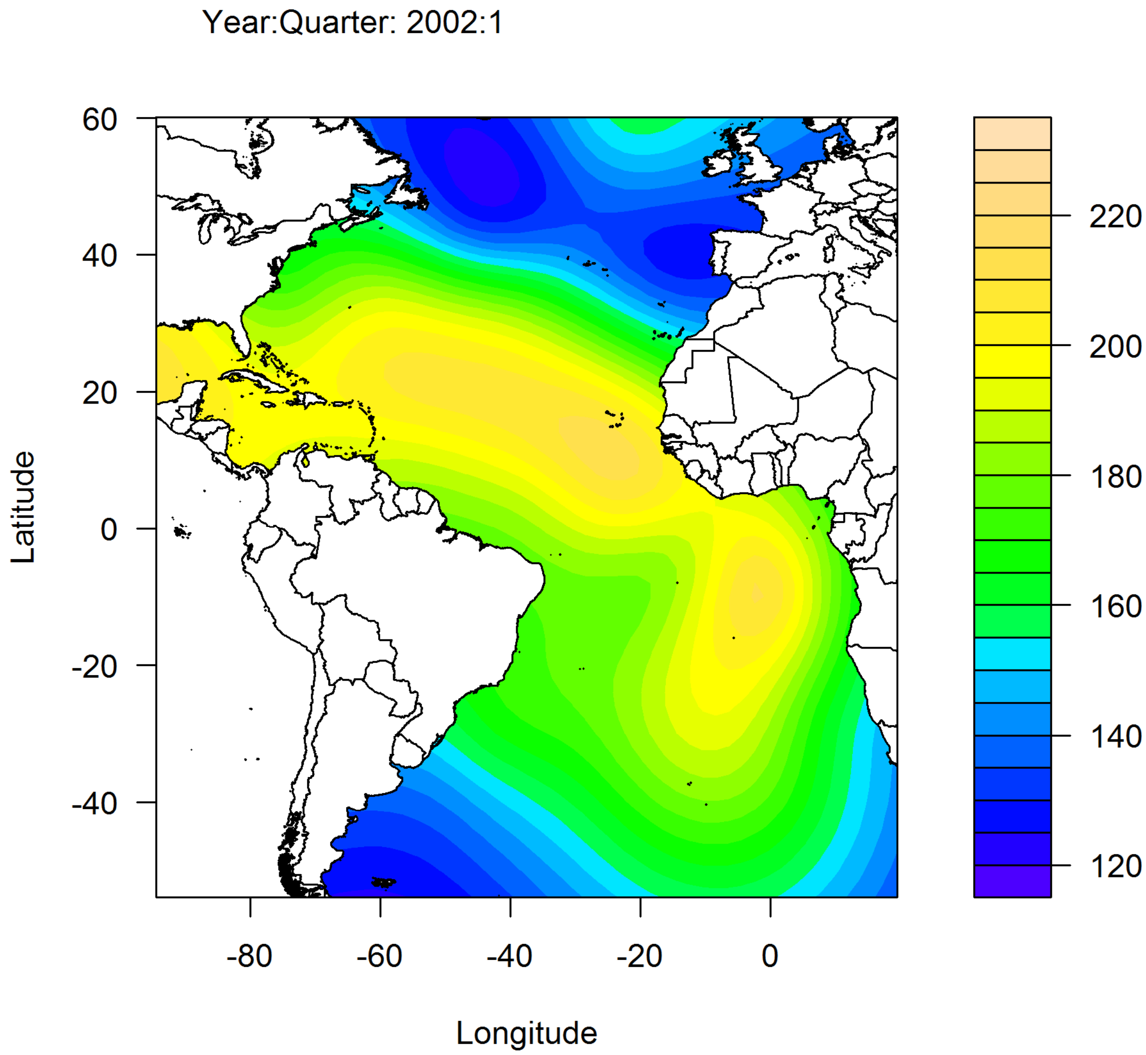

Figure 13. Example of prediction of the catch at size of blue sharks (*Prionace glauca*) caught in the ICCAT convention area (Atlantic Ocean), in this specific case for the 1st quarter of 2012. The predicted values are the result of a Generalized Linear Model (GAM) taking into consideration the smooth terms of the catch location (latitude and longitude) estimated with thin plate regression splines, and the fixed parametric factors of year and quarter. The size range considered was 36-394 cm FL and the sexes were modeled together.

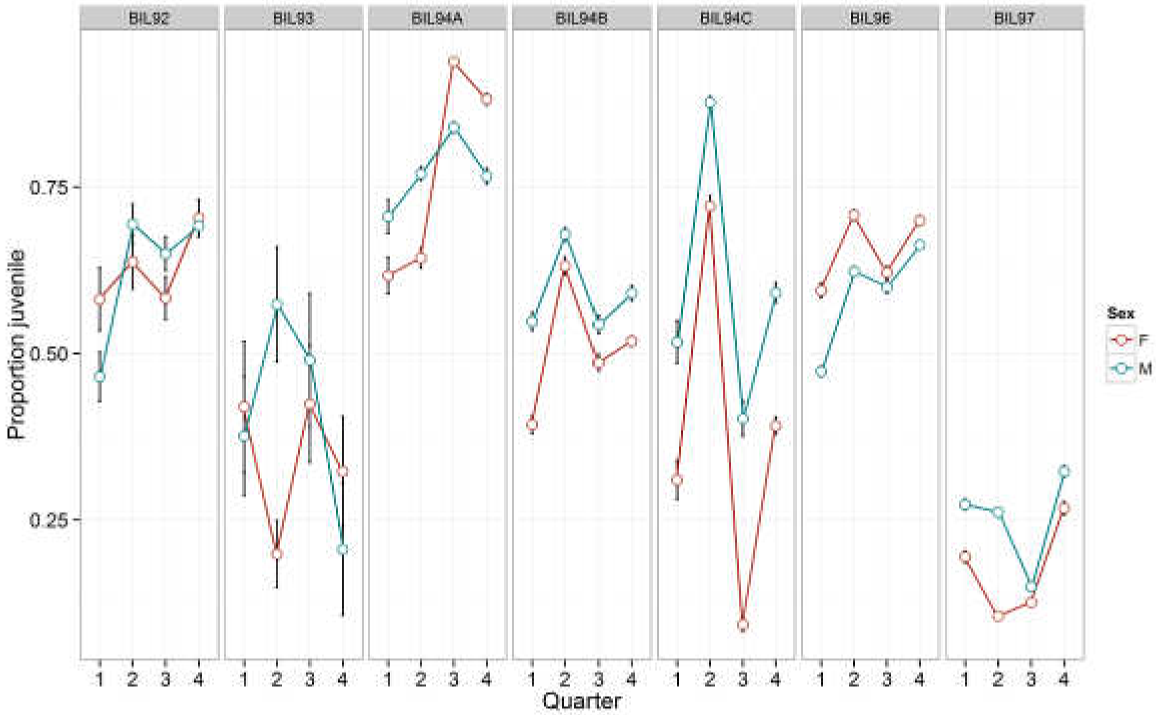

Figure 14. Proportion of juvenile blue sharks (*Prionace glauca*) caught in the ICCAT sampling regions of the Atlantic Ocean in each quarter of the year, during the period 1992-2014. The error bars are ± 1 CI (95%). The size range considered was 36-394 cm FL for both males and females.

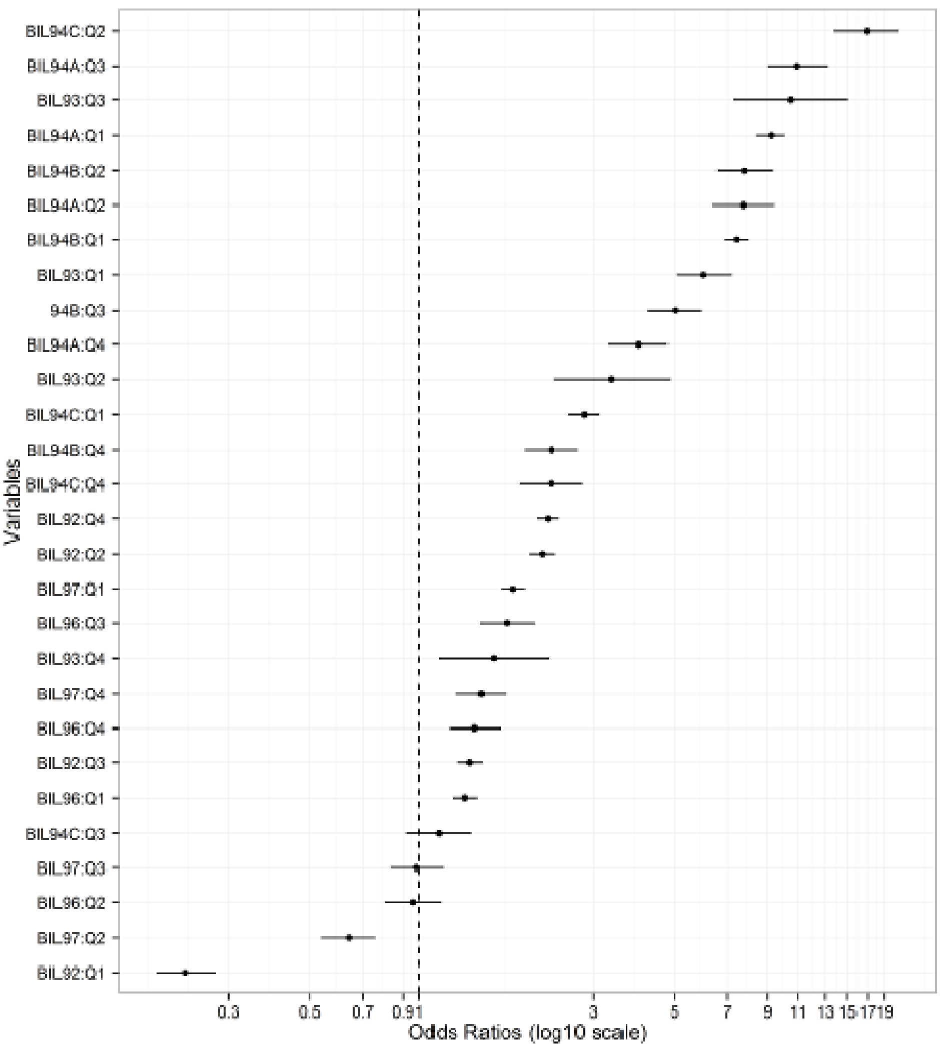

Figure 15. Odds ratios (with 95% confidence intervals) of capturing juvenile blue sharks (*Prionace glauca*) in each of multiple region:quarter combinations. The baseline combination for comparison is BIL92 and quarter 1. The x-axis is represented in a base10 logarithm scale.