A REVISION OF THE SHORTFIN MAKO SHARK CATCH-AT-SIZE IN THE ATLANTIC USING OBSERVER DATA

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SUMMARY

As part of an ongoing cooperative program for fisheries and biological data collection within the ICCAT Sharks Species Group, information collected by fishery observers and scientific projects from several fishing nations in the Atlantic (EU-Portugal, Uruguay, Chinese Taipei, USA, Japan, Brazil and Venezuela) was analyzed. Datasets included information on geographic location, size and sex. A total of 36,903 shortfin mako records collected between 1992 and 2015 were compiled, with the sizes ranging from 30 to 366 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. Most fleets showed unimodal distributions, but in some cases there were bimodal patterns. The distributional patterns presented in this study provide a better understanding of different aspects of the shortfin mako distribution in the Atlantic, and can be used in the 2017 ICCAT SMA stock assessment.

RÉSUMÉ

Dans le cadre d'un programme de coopération continu axé sur la collecte des données halieutiques et biologiques au sein du groupe d'espèces sur les requins de l'ICCAT, des informations recueillies par des observateurs des pêches et dans le cadre de projets scientifiques de plusieurs nations de pêche de l'Atlantique (UE-Portugal, Uruguay, Taipei chinois, États-Unis, Japon, Brésil et Venezuela) ont été analysées. Les jeux de données contenaient des informations sur l'emplacement géographique, la taille et le sexe. Un total de 36.903 registres concernant des requins-taupes bleus prélevés entre 1992 et 2015 ont été compilés, les tailles oscillant entre 30 et 366 cm FL (longueur à la fourche). Une variabilité considérable a été observée dans la distribution des tailles par zone et saison, les plus grandes tailles tendant à se produire dans les régions équatoriales et tropicales et les tailles plus petites dans des latitudes plus élevées. La plupart des flottilles présentaient des distributions unimodales, tandis que dans certains cas des schémas bimodaux ont été observés. Les schémas de distribution présentés dans cette étude offrent une meilleure compréhension des différents aspects de la distribution du requin-taupe bleu dans l'Atlantique et peuvent être utilisés dans l'évaluation du stock de requin-taupe bleu de 2017 de l'ICCAT.

RESUMEN

Como parte de un programa colaborativo en curso para la recopilación de datos biológicos y pesqueros en el seno del Grupo de especies de tiburones de ICCAT, se analizó la información recopilada por los observadores pesqueros y los proyectos científicos de varias naciones pesqueras del Atlántico (UE-Portugal, Uruguay, Taipei Chino, Estados Unidos, Japón, Brasil y Venezuela). Los conjuntos de datos incluían información sobre la ubicación geográfica, talla y sexo. Actualmente, se ha recopilado un total de 36.903 registros de marrajo dientuso entre 1992 y 2015, y sus tallas oscilaban entre 30 y 366 cm FL (longitud a la horquilla). Se observó

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una considerable variabilidad en la distribución de tallas por región y temporada, en la que las tallas más grandes tendían a observarse en las regiones ecuatorial y tropical y las tallas más pequeñas en latitudes más altas. La mayoría de las flotas presentaban distribuciones unimodales, pero en algunos casos existían patrones bimodales. Los patrones de distribución presentados en este estudio proporcionan una mejor comprensión de los diferentes aspectos de la distribución del marrajo dientuso en el Atlántico, y pueden utilizarse en la evaluación del stock de marrajo dientuso de ICCAT de 2017.

KEYWORDS

Catch-at-size, sex ratios, size composition,
Size distribution, shortfin mako, spatial distribution

1. Introduction

The shortfin mako is a widespread pelagic shark species that occurs in temperate and tropical waters of all oceans from about 60ºN to 50°S (Compagno, 2001). Like other Lamnidae sharks, it is an endothermic species that uses a heat-exchanging circulatory system to maintain muscle and visceral temperatures above that of the surrounding water, which allows a higher level of activity (Carey et al., 1981; Bernal et al., 2001). Tagging studies in the northwest Atlantic have shown that shortfin makos can make extensive migrations of more than 3,000 km (Casey and Kohler, 1992), even thought there is the suggestion that trans-Atlantic migrations are not as common as in the blue shark.

The shortfin mako is one of the most valuable shark species for its high quality meat, which can be utilized fresh, frozen, smoked and dried-salted for human consumption. Big-game sports angling for this species is widespread, and shortfin makos have become the subject of ecotourism diving in some areas in recent years (Compagno, 2001). The shortfin mako is an important and valuable species for pelagic longlines, drifting and set gillnets and on hook-and-line fisheries. The Ecological Risk Assessments carried out for pelagic sharks in the Atlantic in 2010 and 2012 (Cortés et al., 2010; Cortés et al., 2012) showed that the shortfin mako was one of the most vulnerable of all species analyzed, due to its relatively low productivity and high susceptibility. The last shortfin mako stock assessment in the Atlantic (North and South stocks) was carried out by ICCAT in 2012 (Anon., 2012). The results indicated, in general, that the status of both stocks seemed healthy with a low probability of overfishing. However, the models also showed inconsistencies between estimated biomass trajectories and CPUE trends, producing high uncertainties in the estimates, particularly for the South Atlantic. The high uncertainty in catch estimates and deficiency of some important biological parameters were obstacles for obtaining reliable estimates of stock status (Anon., 2012).

In 2017 ICCAT has scheduled a new shortfin mako stock assessment (North and South Atlantic stocks). The main objective of this paper is to provide a contribution to this 2017 stock assessment, by analyzing detailed catch-at-size information from the major longline fleets that target tunas or swordfish in the Atlantic and capture shortfin mako as bycatch. The specific objectives of the paper are to 1) analyze the distribution and seasonal patterns of the shortfin mako catch-at-size, 2) provide time series trends by region and fleet and 3) analyze the distribution of the sex ratios. The results can be considered for integration in the 2017 stock assessment models, particularly the SS3 model that is being developed for the North Atlantic.

2. Materials and methods

2.1. Data collection

Shortfin mako records and data were recorded by scientific observers and port samplers working on national data collection programs and scientific projects. Data came from 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*), the Brazil observer program and Venezuela (*ICCAT's EPBR-Venezuelan Pelagic Longline Observer Program*).

Data were collected across a wide geographical range. For analysis purposes, the two hemispheres (stocks) were separated at the 5ºN parallel, as recommended in the ICCAT Manual for shark species (ICCAT, 2006-2016). Furthermore, the study area was divided into eight major areas taking into consideration the ICCAT sampling areas for sharks (ICCAT, 2006-2016).

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 recommended by the ICCAT Sharks working group (Anon., 2014).

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 size distributions were plotted and compared between years, fleets and stocks. The annual trends of the mean catch-at-size were also plotted and analyzed for fleets and stocks. The sex ratios were calculated and plotted using 5*5 degree squares.

The analysis for this paper was carried out using the R language for statistical computing version 3.2.0. (R Core Team, 2015). 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), "ggplot2" (Wickham, 2009), "maps" (Becker et al., 2013), "mapplots" (Gerritsen, 2013), "maptools" (Bivand and Lewin-Koh, 2013), "nortest" (Gross and Ligges, 2012), "perm" (Fay and Shaw, 2010), "plyr" (Wickham, 2011), "rgdal" (Bivand, et al., 2013) and "shapefiles" (Stabler, 2013).

3. Results

3.1. Distribution of the catch-at-size

A total of 36,903 shortfin mako shark specimens were recorded, reported and considered within the scope of this study, specifically 17,705 from Portugal, 6,805 from Uruguay, 6,465 from the USA, 3,348 from Taiwan, 1,477 from Japan, 423 from Venezuela and 413 from Brazil. The specimens ranged in size from 30 to 366 cm FL, covering a wide range of the species size range (**Figure 1, Figure 2**).The median sizes and inter-quartile ranges tended to be larger for the males compared to females (**Figure 3**). However, the larger specimens (outliers) were usually female shortfin mako specimens (**Figure 3**).

Considerable variability was observed in the size distribution of males and females in the various Atlantic regions (**Figure 4**). In areas such as BIL91 and BIL 92 (NW-Atl) and BIL94A (N-central Atl) there was considerable variability between males and females (**Figure 5**). On other areas as BIL94B and BIL94C (NE-Atl) and BIL96 and BIL97 (South-Atl) the size differences between sexes was less evident. The larger median sizes for both sexes occurred in area BIL93 in the NW-Atl (**Figure 5**).

Size data were not normally distributed (Lilliefors test: $D = 0.0437$, p-value < 0.001) and the variances were heterogeneous between regions (Levene test: $F = 100.37$, df = 7, p-value < 0.001) but not between sexes (Levene test: $F = 0.0663$, df = 1, p-value = 0.7967). Using univariate non-parametric statistical tests revealed that sizes were significantly different among regions (Permutation test: chi-squared = 2464.4, df = 7, p-value < 0.001), sexes (Permutation test: chi-squared = 183.24, df = 1, p-value < 0.001) and quarters (Permutation test: chi-squared = 345.8, df = 3, p-value < 0.001). In terms of size distribution, for most fleets and on both stocks the size data seemed unimodal, except in some cases (e.g., USA in the North Atl) where some bimodal distribution is apparent (**Figure 6**).

3.2. Annual trends in the catch-at-size

The time series of the catch at size was relatively stable for the North Atlantic. By the contrary, there was a general decreasing trend in the South Atlantic (**Figure 7**). There was considerable variability on the time series trends by fleet, which are shown in **Figure 8**.

3.3. Distribution of the sex ratios

Of the overall shortfin mako size data, 19,769 specimens had the sex recorded. Of those, 8,940 (45.2%) were females and the remaining 10,829 (54.8%) were males. There were some apparent sex-ratio segregations, for example with more males in the NW and SW regions, and more females in the tropical NE (**Figure 9**). In some areas of the Atlantic there was variability in the sex ratios according to the seasonality (**Figure 10**).

4. Discussion

This work provides a comprehensive revision of the shortfin mako catch at size distribution using data from fishery observer programs of the Atlantic Ocean and represents an important contribution to the study of the spatial and seasonal dynamics of this species. Significant differences were found in the size-frequency distributions, time series trends and sex ratios.

There seems to be some latitudinal distribution of the shortfin mako in the Atlantic, 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. This pattern is similar to what was found for the blue shark (Coelho et al., 2015), but opposite to other pelagic shark species as the bigeye thresher (Fernandez-Carvalho et al., 2015).

Casey and Kohler (1992) suggested that the core distribution of shortfin makos in the northwest Atlantic is between 20-40°N bordered by the Gulf Stream in the west and the mid-Atlantic ridge in the east. In the northeast Atlantic it is presumed that the Strait of Gibraltar might be a nursery ground (Buencuerpo et al., 1998; Tudela et al., 2005). The area between 17° to 35°S off the coast of Brazil seems to be an area of birth, growth and mating in the southwest Atlantic (Amorim et al., 1998). Our study extends those previous observations from other authors, as the entire temperate area of the North and Central Atlantic seem to be a nursery for the species, especially the areas closer to continental and insular shelf waters. In the South Atlantic both the southeast and southwest areas also seem to be nurseries for the species due to the large proportions of juveniles.

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 fleet distribution and selectivity. Additionally, some of the variability observed in the fleet time series analysis may be explained by lower sample sizes in some years. While our study provides a general overview of the size distribution at a wide Atlantic scale, it is worth noting that there are probably finer scale effects and local variability patterns taking place that are not likely to be captured in such large scale 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. These general distributional patterns presented can be used in future stock assessments of the species, particularly in the upcoming 2017 ICCAT SMA assessment, and help managers adopt more informed and efficient conservation measures.

5. Acknowledgments

This work was carried out as part of a cooperative study conducted by the ICCAT Shark species group. Sampling and data collection from the Portuguese fishery were obtained and funded within the scope of the EU Data Collection Framework. Sampling from Uruguay was conducted by fishery observers from PNOFA. Sampling from Venezuela was conducted by scientific observers of the ICCAT sponsored Enhanced Program for Billfish Research (EPBR) in Venezuela. The authors are grateful to all the fishery observers and longline skippers from the nations involved in this study. R. Coelho is supported by an Investigador-FCT contract from the Portuguese Foundation for Science and Technology (*FCT, Fundação para a Ciência e Tecnologia*) supported by the EU European Social Fund and the *Programa Operacional Potencial Humano* (Ref: IF/00253/2014).

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Table 1. Current sample available for the revision of the shortfin mako catch-at-size in the ICCAT area from detailed observer data. The values refer to counts of shortfin mako specimens with size information, by year and reporting fleet.

Year	**Fleet**							**Total**
	Brasil	**EU.Portugal**	**Japan**	**Taiwan**	**Uruguay**	**USA**	**Venezuela**	
1992						44		44
1993						226		226
1994						218	8	226
1995						306	46	352
1996						33	21	54
1997		373	377			200	17	967
1998		628	180		10	67	15	900
1999		843	12		18	111	2	986
2000		411	7		14	215	2	649
2001		317	66		32	99	8	522
2002		579	80	29	122	162	4	976
2003		164	17	58	828	173	13	1253
2004		737	28	58	1075	489	6	2393
2005	9	338	32	70	581	180		1210
2006	2	295	51	868	360	341	4	1921
2007	260	560	57	175	535	364	6	1957
2008	36	659	100	175	488	348	1	1807
2009		835	78	297	931	895	2	3038
2010	106	1610	77	175	671	445	6	3090
2011		5410	89	369	645	455	43	7011
2012		2564	68	332	415	352	133	3864
2013		709	139	224	79	435	86	1672
2014		324	195	484	1	307		1311
2015		349	91	34				474
Total	413	17705	1744	3348	6805	6465	423	36903

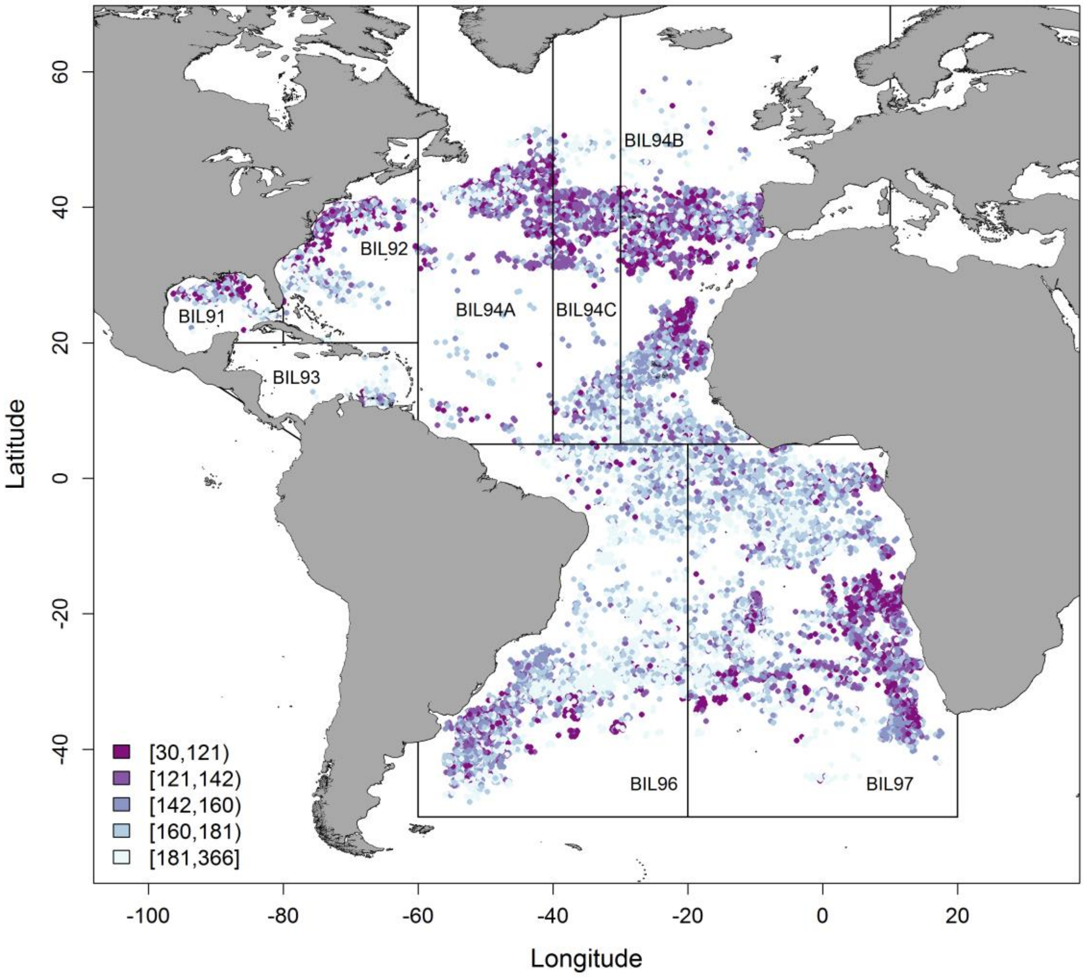

Figure 1. Location and catch-at-size (FL, cm) of the shortfin mako (*Isurus oxyrinchus*) recorded for this study in the Atlantic Ocean. The color scale of the dots represents specimen sizes, with darker colors representing smaller specimens and lighter colors larger specimens. The categorization of size 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.

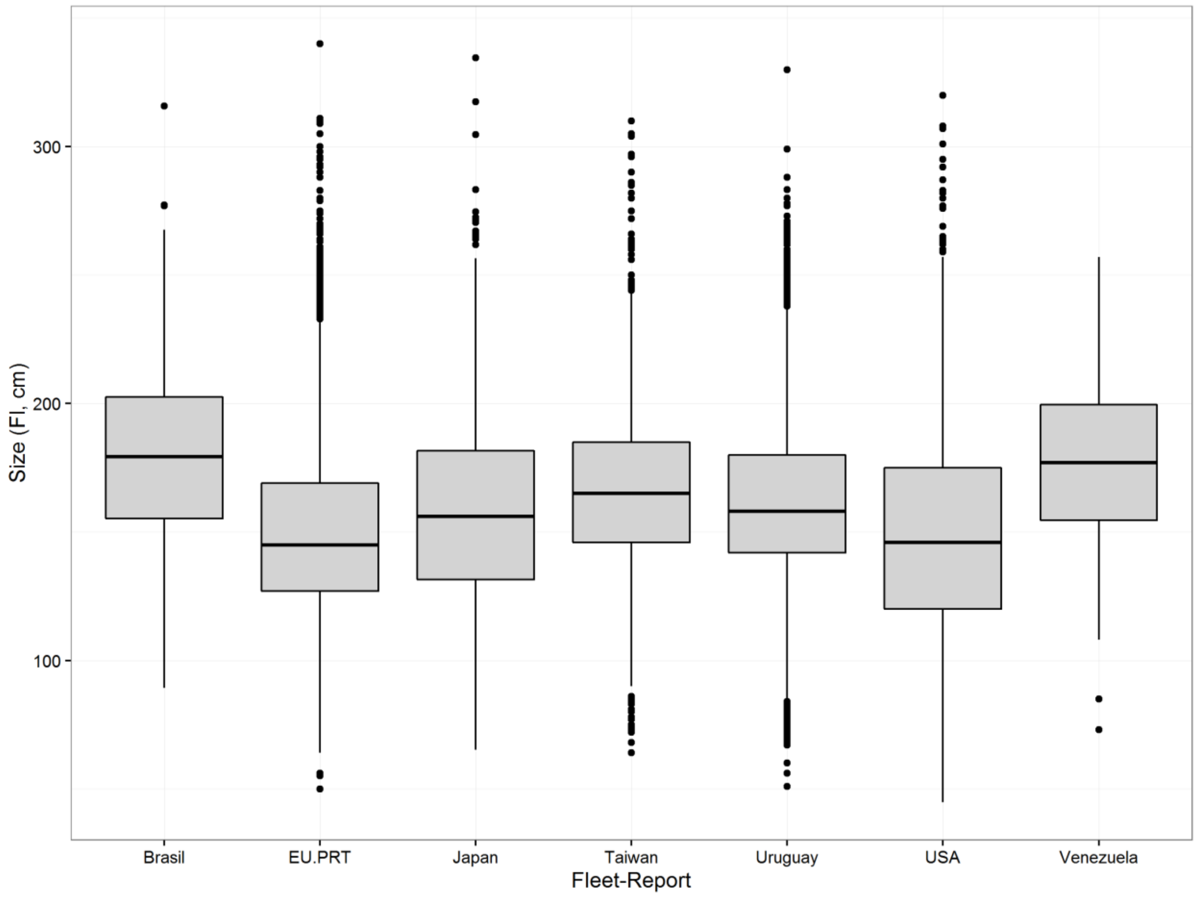

Figure 2. Boxplots with the size distribution of the shortfin mako size ranges from the various fleets. The middle bar represents the median, the box represents the inter-quartile range, the vertical lines represent the non-outlier range and the points represent outliers.

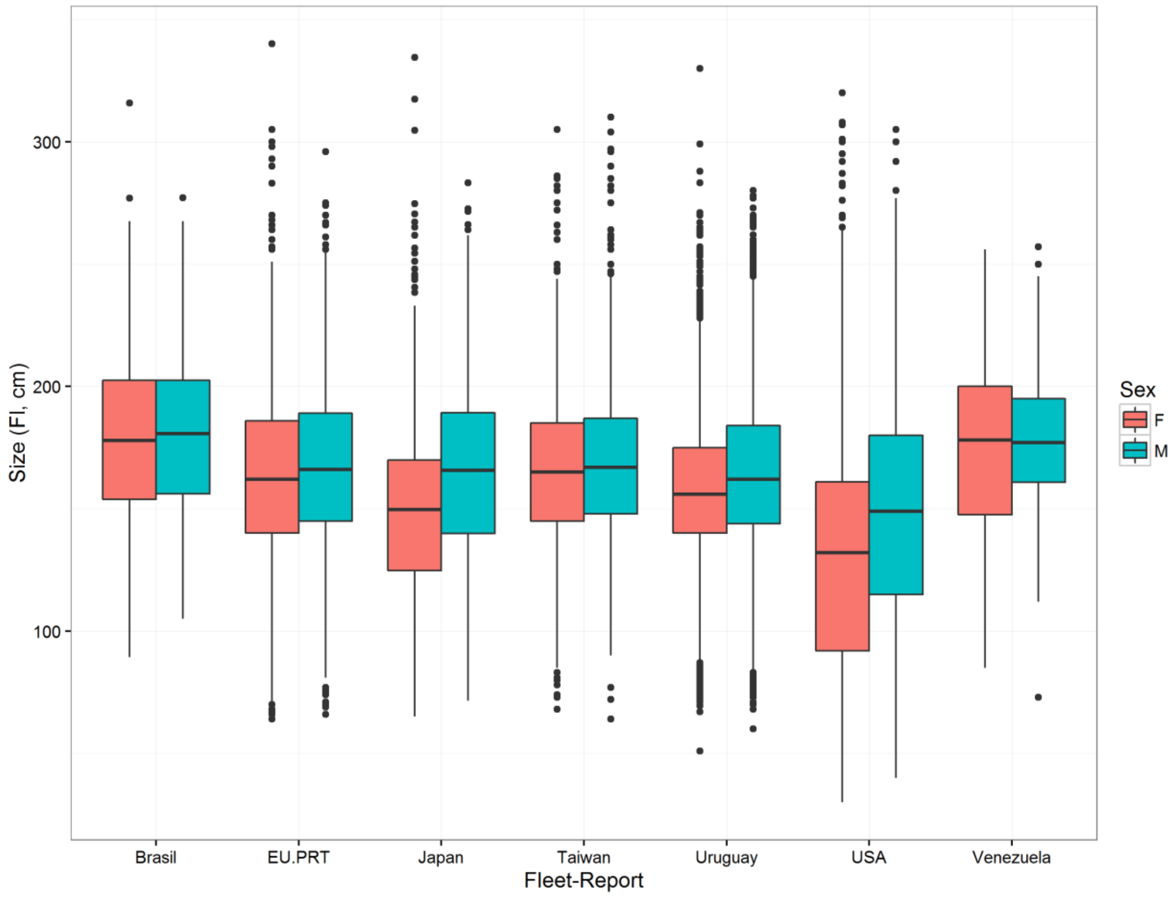

Figure 3. Boxplots with the size distribution of the shortfin mako size ranges from the various fleets, categorized by sex. In each boxplot the middle bar represents the median, the box represents the inter-quartile range, the vertical lines represent the non-outlier range and the points represent outliers.

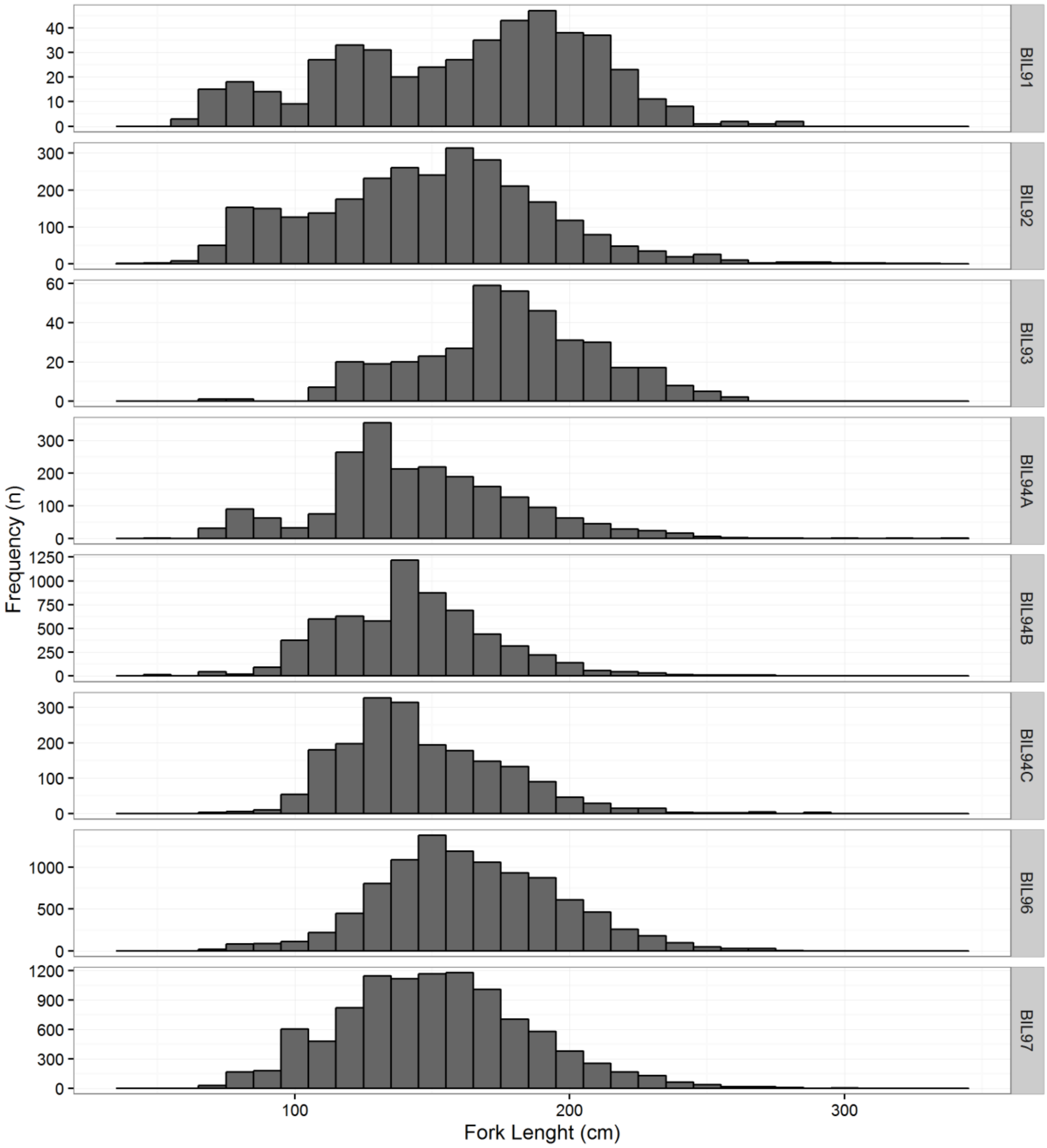

Figure 4. Size-frequency distributions of shortfin mako in the ICCAT sampling areas of the Atlantic Ocean.

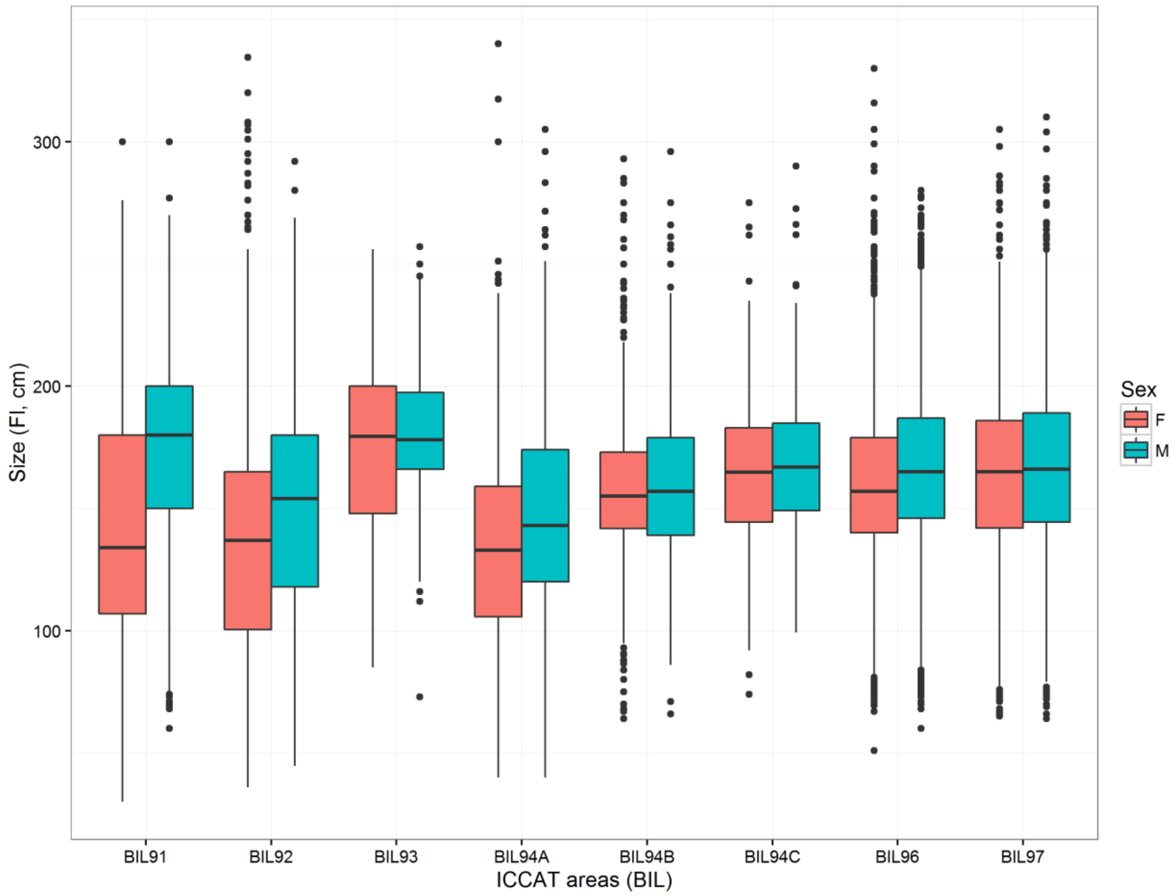

Figure 5. Boxplots with the size distribution of the shortfin mako size ranges from the various ICCAT sampling regions for sharks, categorized by sex. In each boxplot the middle bar represents the median, the box represents the inter-quartile range, the vertical lines represent the non-outlier range and the points represent outliers.

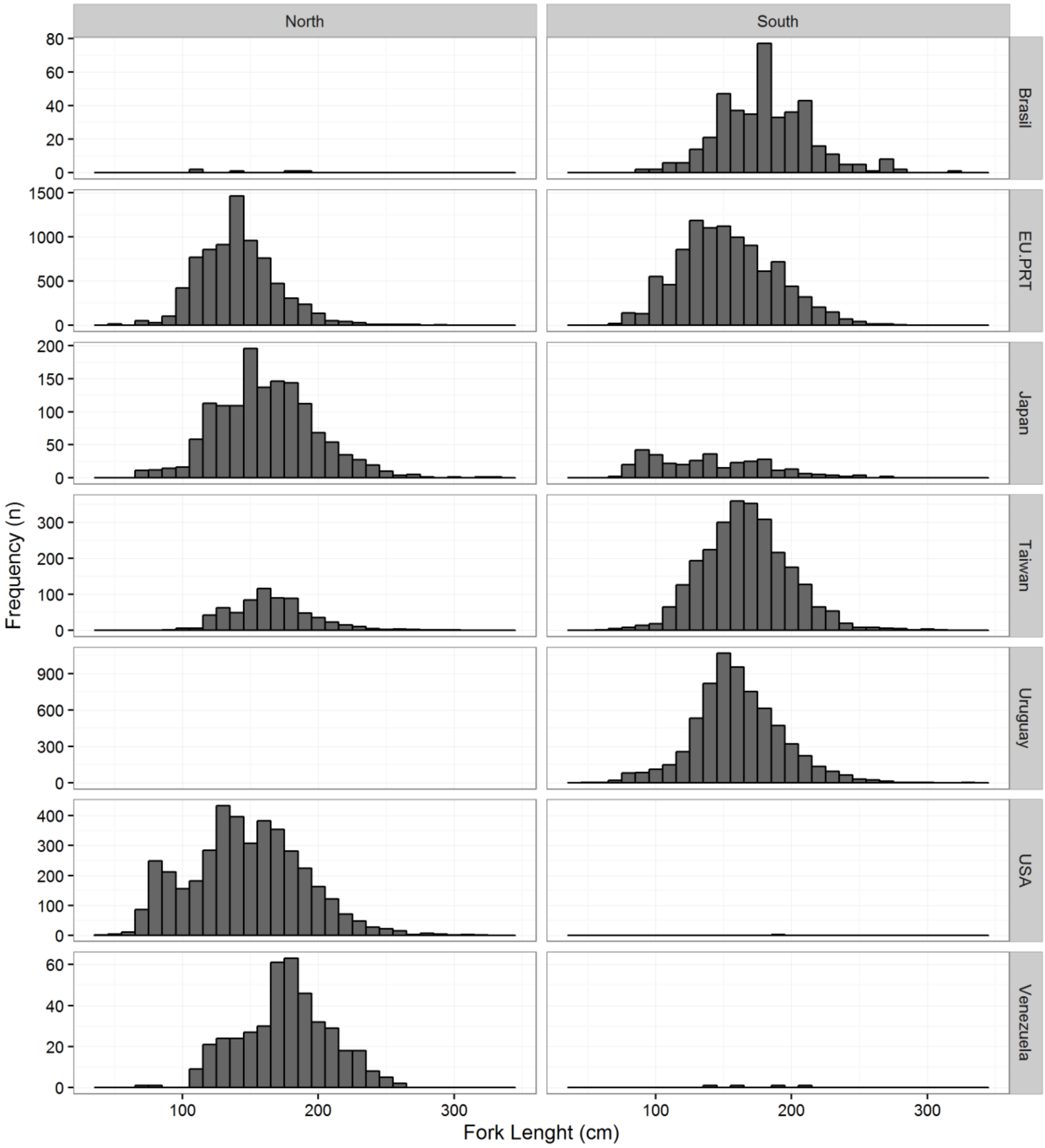

Figure 6. Size-frequency distributions of shortfin mako by fleet and hemisphere in the Atlantic Ocean.

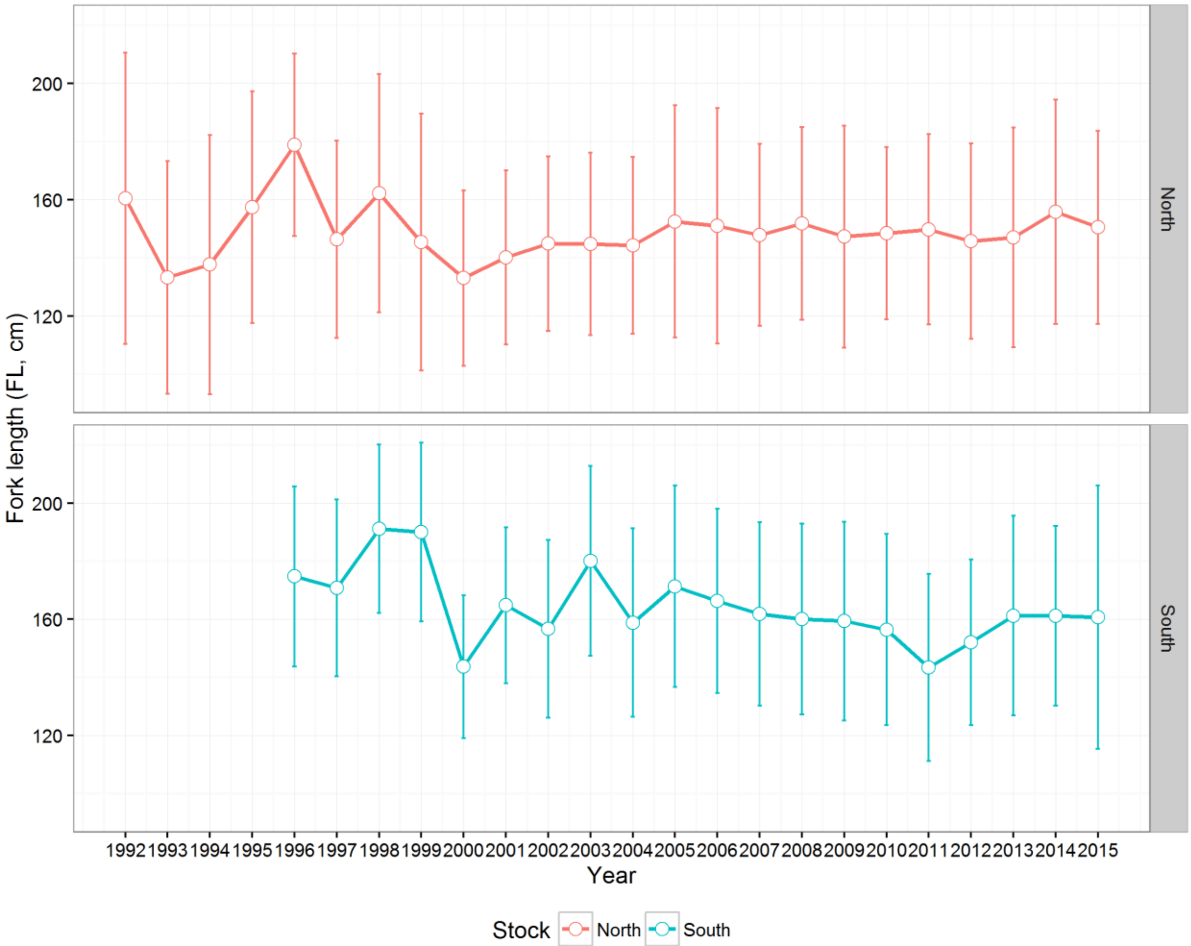

Figure 7. Times series of the mean sizes of shortfin mako in the two stock areas (north and south Atlantic, separated by 5ºN) during the period 1992-2015. The error bars are ± 1 standard deviation.

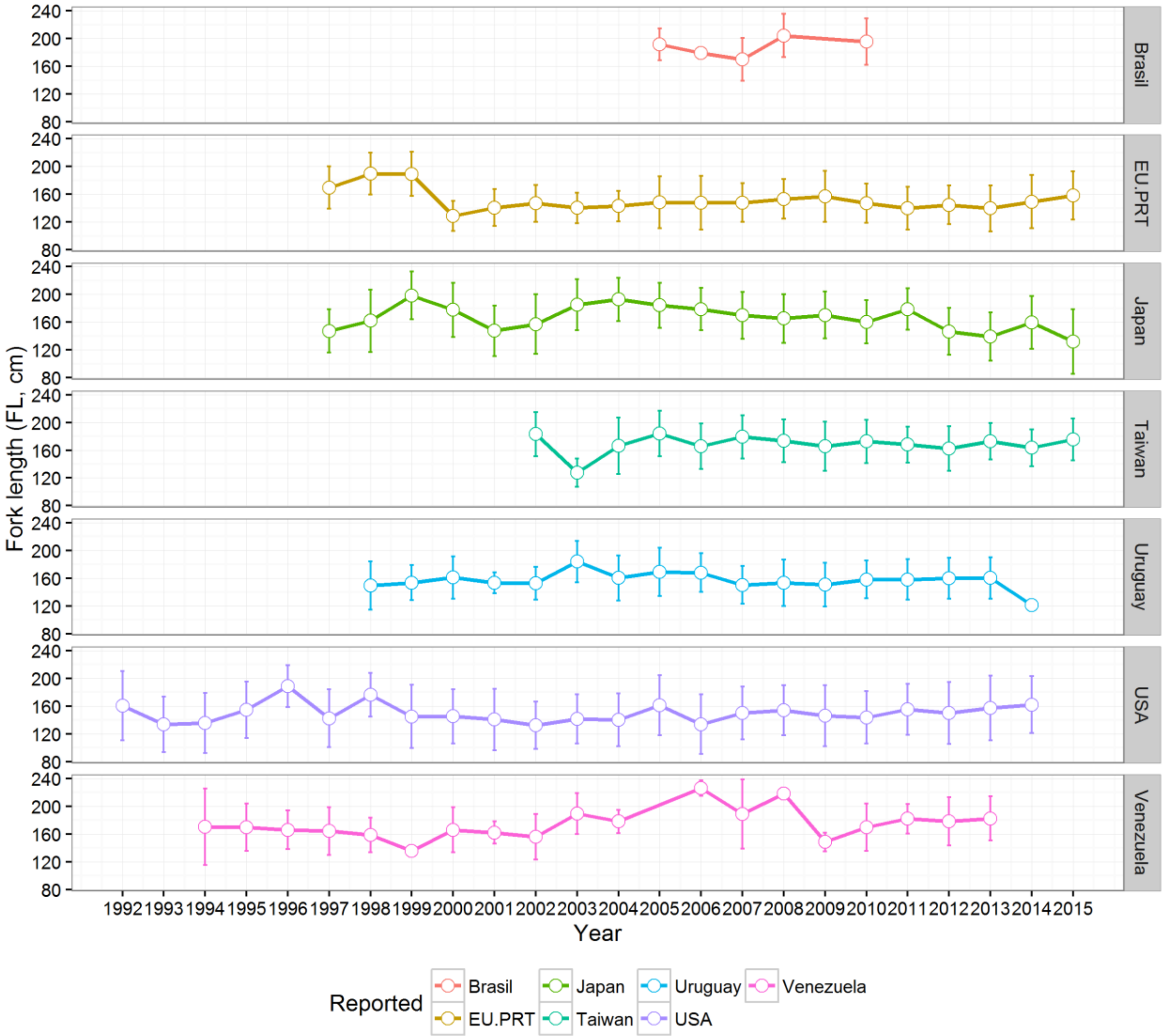

Figure 8. Times series of the mean sizes of shortfin mako by the various fleets (period of the time series are specific for each fleet). The error bars are ± 1 standard deviation.

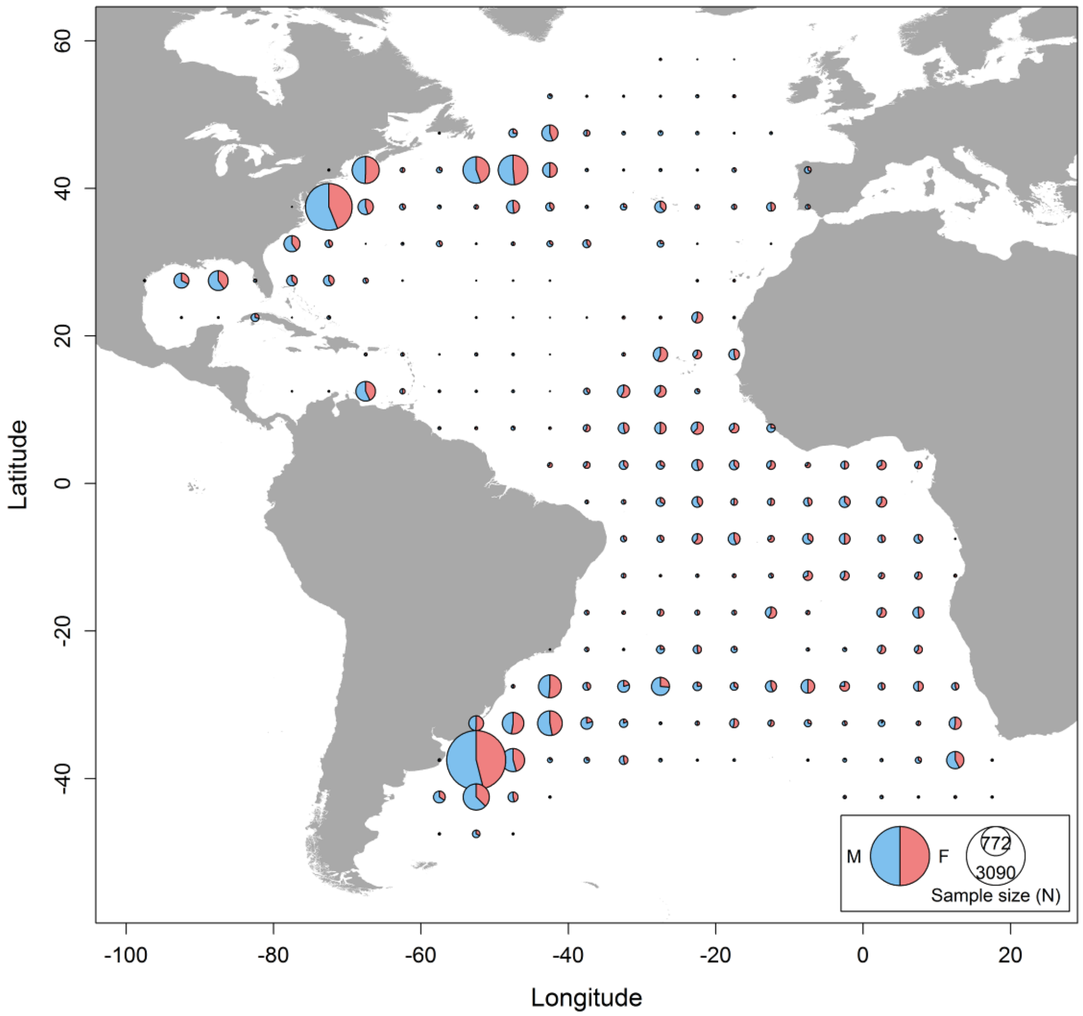

Figure 9. Shortfin mako sex ratios recorded in 5ºx5º squares during this study (period 1992-2015). Circle sizes are proportional to the sample size (N) in each square.

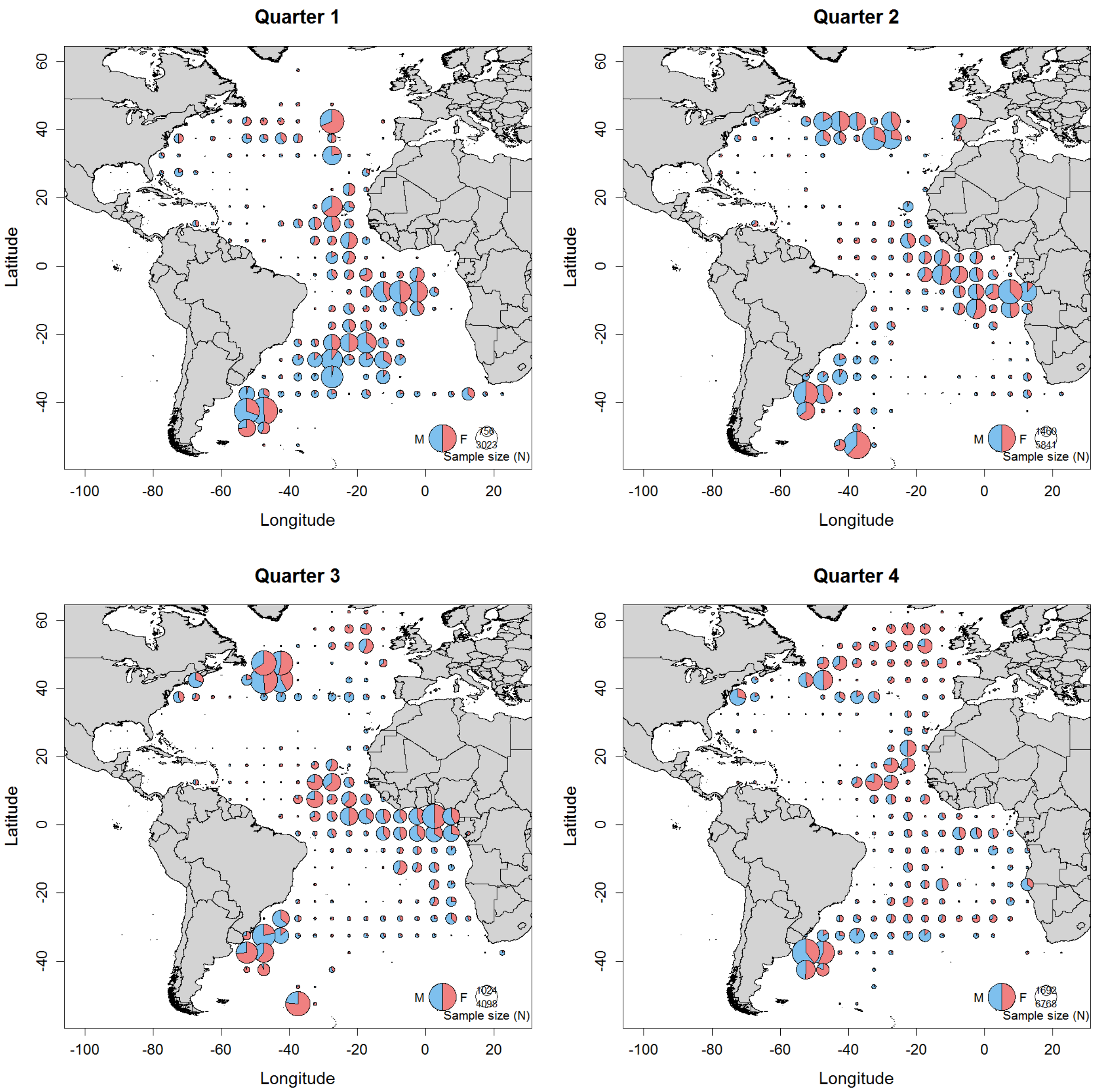

Figure 10. Shortfin mako sex ratios recorded in 5ºx5º squares during this study in each quarter of the year (period 1992-2015). Circle sizes are proportional to the sample size (N) in each square.