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DATA-MINING OF BLUE SHARK LENGTH OF NORTH AND SOUTH ATLANTIC STOCKS FROM THE SPANISH SURFACE LONGLINE 1997-2021

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SUMMARY

*The paper summarizes the length data-mining carried out in recent years in order to obtain a broad overview of the average length over time of the blue shark (*Prionace glauca*) between years 1997-2021 for the North and South Atlantic stocks. The data-mining was carried out through an intense compilation of records from samples on board commercial trips, experimental and tagging surveys, personal notes from skippers that were voluntarily provided for this scientific contribution through a collaborative science action, as well as through sampling during landings. The length data series was analyzed using GLM models to obtain relative and standardized trend of the mean length over time. The results showed a stable trend of the mean length and a slightly upward in the most recent period for both stocks.*

RÉSUMÉ

Le présent document résume l'extraction des données de longueur réalisée ces dernières années afin d'obtenir une vue d'ensemble de la longueur moyenne dans le temps des stocks de requin peau bleue (Prionace glauca) *de l'Atlantique Nord et de l'Atlantique Sud entre 1997 et 2021. L'extraction de données a été réalisée grâce à une compilation intensive des registres d'échantillons à bord des navires commerciaux, dans le cadre de campagne expérimentales et de marquage, des notes personnelles des capitaines qui ont été volontairement fournies à des fins scientifiques par le biais d'une action scientifique collaborative, ainsi que par le biais d'un échantillonnage pendant les débarquements. La série de données sur la longueur a été analysée à l'aide de modèles GLM afin d'obtenir une tendance relative et standardisée de la longueur moyenne au fil du temps. Les résultats ont montré une tendance stable de la longueur moyenne et une légère augmentation au cours de la période la plus récente pour les deux stocks.*

RESUMEN

*El documento resume la minería de datos de talla de la tintorera (*Prionace glauca*) realizada en los últimos años para obtener una visión amplia y global sobre la tendencia de la talla media entre los años 1997-2021 para los stocks norte y sur del Atlántico. La minería fue realizada mediante intensa recopilación de registros de muestreos a bordo de buques comerciales, en campañas experimentales y de marcado, en notas personales de patrones que fueron cedidas voluntariamente con fines científicos mediante una acción de ciencia ciudadana-colaborativa, así como mediante registros en desembarcos. Se analizó la serie de datos de talla usando modelos GLM para obtener la tendencia relativa-estandarizada de la talla media a lo largo de los años. Los datos mostraron una tendencia estable de la talla media y ligeramente ascendente en periodos más recientes, para ambos stocks.*

KEYWORDS

Blue shark, Length data, Sex-ratio

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1. Introduction

Pelagic shark species can be fished by commercial and recreational fisheries in many countries of the North and South Atlantic. Some important recreational fisheries have been described in the scientific literature since decades ago, as well as in artisanal fleets developed in some countries (i.e. Amponsah *et al.* 2022) which descriptions and data reports are regularly very scarce or omitted. In the scope of the ICCAT tuna and tuna-like fisheries, the pelagic sharks are commonly considered mainly as by-catch of oceanic pelagic longlines (Buencuerpo *et al.* 1998, Simpfendorfer *et al.* 2002). However this species can be also found in other fisheries and gears, including recreational making blue shark the most abundant and frequently caught of large pelagic shark species landed at recreational and tournament fishing (Campana *et al*. 2006, Sippel and Kohin, 2013, Wögerbauer *et al*. 2016).

Blue shark is a highly migratory species considered as one of the most successful in the epipelagic ecosystem, with a very high abundance and biomass and a broad geographic distribution in different oceans, regularly found between 50ºN and 50ºS. However, it has been also known to appear at higher latitudes (Compagno 1984). The high prevalence of blue shark in catches of many oceanic fleets, including a wide variety of gears, zones and seasons as well as in fisheries carried out over the course of many decades, it may be attributed to the great abundance of this species in the epipelagic ecosystem, the reproductive strategy and the high renovation rate described for Atlantic, Indian and Pacific areas by different authors. It was also pointed out the high abundance and biomass of this species in the assessments carried out to date of the different stocks. Spatial segregation by sex and length is considered to be an intrinsic attribute of many large pelagic bony fish such as tuna and tuna-like species, but also of the large pelagic shark populations such as the blue shark.

The Spanish surface longline fishery was developed since late 1970's in the North Atlantic targeting mainly swordfish (*Xiphias gladius*), while in the South Atlantic it gained importance after 1986 (Mejuto *et al.* 1997). Since the 1990's the discards of blue shark have radically disappeared in this fleet. Freezing systems introduced in the boats allowed a full retention. Changes in markets of the two most abundant species (swordfish and blue shark) and other factors also moved the skippers towards full retention on board with the combination of both species (swordfish and blue shark) given rise to the integral use of the blue shark catches and their derivatives (Mejuto 2004). The traditional surface longline fishing in the Northern stock later continued with a fishing strategy based on the economic maximization of the activity without clearly defining the target species in many trips, maintaining a bi-specific strategy in many cases and changing the target by fishing trip and/or year. The blue shark and swordfish catches are related to their abundance but also to market factors, prices between species as well as other such as type of boat, domestic regulations implemented, etc. The behaviour and impact of similar changes over time on the fishing strategy have already been described in abundant ICCAT literature on this and other longline fleets targeting swordfish and/or other species, including descriptions on the catches reported by fleet and the standardized CPUE calculations. Important changes in the gear configuration also took place in the early 2000's in the Spanish fleet when the multifilament style traditionally used was replaced by the American-style monofilament which continues to be the preferred style to date (Mejuto and De la Serna 1997, 2000; Mejuto *et al.* 2000). More information about the history of this fishery can be found in the abundant ICCAT literature previously presented to the SCRS.

The main objective of this paper is to present the length information recovered from different sources and to provide a contribution to the 2023 blue shark stock assessment, comparing the length information in terms of years, seasons and fishing areas.

2. Material and methods

A collaborative effort was made to recover and analyze records with information of length and sex of blue shark caught by the Spanish surface longline fleet in the Atlantic. The data refers to records recovered for years 1997 to 2021. The data was collected by scientific samplers onboard, skipper's personal records voluntarily provided for this scientific contribution and also from records during port sampling. Information on the length, weight and sex was recorded for each specimen. Other information related to the set such as the gear-style, the month and the geographical position (considering 5x5 degree grids) was also recovered and recorded. Observations allocated according to the geographical position were classified into Northern and Southern Atlantic stocks for descriptive and analytical purposes.

All specimens were length measured (FL, fork length in cm). However, some records from the skippers were provided to us in individual weight by using on-board a conversion between lengths to weights (Kohler *et al.* 1995) to record the weight of catches on board. For these last cases with only available individual weight, the same weight-length relationship was inversely applied to recover the original FL taken by the skippers. The lengths were grouped in 5cm length classes. The yearly length frequency distributions were created for the Northern and Southern stocks (separated by 5º N). Mean lengths were plotted by year and stock. Sex was identified according to the presence or absence of claspers and recorded when possible, otherwise they were classified as unknown (Unk). There also were included more variables because the priority was to assess the trend and inter-annual variability by stock. The sex-ratio was obtained (years combined) as the percentage of females present with regard to the total number sexed. Male *versus* female contributions were also plotted by each 5ºx5º square.

The software used for the analyses of length data trends was R 4.2.2. The standard mean length and its variability along the years were obtained using the function *lm* of the *Lsmean*s package. The base case model used was:

Lm (Length ~ Y+La+Lo+Q+G+La:Lo)

Y= year effect. Q= quarter effect (1: January-March; 2: April-June; 3: July-September; 4: October-December). La = latitude effect every 5º (the range of 5º is represented by the value closest to the Equator). Lo= longitude effect every 5º (the range of 5º is represented by the value closest to the Greenwich Meridian). G= gear effect (1: traditional multifilament; 3: American-style monofilament). La:Lo= represents the interactions between latitude and longitude factors. Sensitivity analyzes were also carried out using other model approaches, definitions and categorizations for the geographical factors. The trend of the mean length over time was expressed in relation to the maximum value of the series.

3. Results and discussion

A total of 626,671 length observations (FL cm) of *Prionace glauca* were recovered from the different sources for the full period 1997-2021; 453,504 observations for the Northern stock and 173,167 for the Southern stock (**Figure 1)**. **Table 1** summarizes the number of observations, total and by sex, the mean length and standard deviation, during the period 1997-2021 for Northern and Southern stocks.

Tables 2 and **3** show the yearly number of observations available of the length variable for the North and South stocks by sexes combined (females+males+unknown), including descriptive statistics (FLmax, FLmin, FLmean, Standard Deviation and CVs). For the North Atlantic stock, the length range recorded was between 52 and 347 cm, with a mean length of 140.30 cm (Std. dev =40.87), being mean lengths of 138.12 cm (Std. dev =40.77) and 148.76 cm (Std. dev =41.81) for females and males, respectively. A length range between 57 and 327 cm, with a mean length of 194.37 cm (Std. dev =28.36), was found for the South stock with mean lengths of 193.73 cm (Std. dev =25.17) and 191.83 cm (Std. dev =29.48) for females and males, respectively.

The authors warn the unbalanced sampling available between both stocks analyzed, in terms of number of observations and length ranges as well as the different geographical representativeness, the diversity of the lengths and the different histories of the fisheries in each stock. While for the Northern stock there is a huge amount of samples recovered mainly from eastern-temperate and central-temperate areas and a wide spatial coverage was achieved, samples for the Southern stock are mostly from tropical areas and there is a relatively lower availability of records. Therefore, comparisons should not be carried out between the length distributions of North and South based on the present data, nor should these distributions be generalized to other areas or fleets. A very few records of year 2016 are available for the Southern stock. Although those records are included in descriptive tables, they were omitted for modeling approaches. In addition, during the year 2019 no samples were available for the Southern stock.

Table 4 and **5** shows the number of length observations available and descriptive data of the length distribution by quarter for the period 1997-2021, for Northern and Southern stocks. **Figure 2** shows the length frequency, total and by sex, for the Northern and Southern stocks. **Figures 4** and **5** are representing the length distributions by year for each stock. Taking into consideration a suggestion from the 2015 working group, the size distribution obtained for the Northern stock is also presented, separated by 30ºN latitude (**Figure 6**).

A wide variability was observed in the length distributions of both male and female blue sharks among stocks. Regularly, larger blue sharks tend to occur in equatorial and tropical regions and relatively smaller specimens in higher latitudes in temperate waters as occurs in the Northern in North-east off the Iberian Peninsula where several fisheries are operating and where those specimens are found. Nursery areas in the Atlantic seem to occur in the temperate South-east off South Africa and Namibia, in the South-west off Southern Brazil and Uruguay (Coelho *et al.* 2017). Parturition is reported to occur in the tropical North-east off West Africa (Coelho *et al.* 2017, Castro and Mejuto 1995) and in cold-productive Southern waters, which may also act as nursery grounds for young juveniles (Mas *et al.* 2023). Adults are typically found in deeper, offshore waters, while newly born and juvenile blue sharks are found in near shore environments, such as bays and estuaries and later traveling long distances described in the abundant tagging-recapture data recorded since 1960's to reach oceanic feeding or mating grounds.

The global sex-ratio obtained for the total Atlantic was 45% of females. For the North and South stock it was 46% and 33% of females, respectively. **Figure 3** represents the sex-ratio by grid for the Atlantic Ocean. The spatial variability in sex ratios is evident suggesting a sexual segregation at least in this data set from surface longline. It is known that the distribution and movements of individuals leads to sexual segregation, with thermal preferences between sexes in addition to being strongly influenced by the currents and also conditioned by the distribution of their prey. Large females tend to have greater habitat overlap with small juveniles than large males, more defined by temperature than productivity preferences (Druon *et al.* 2022). According to Li *et al.* (2020) females may be distributed somewhat closer to the surface than males in some tropical areas and as well as it is also indicated that males will outnumber females in fishing areas targeting tuna species (Hazin 1994). Such vertical stratification by sex could partially explain the different sex-ratios observed by areas.

Since the total length distribution in the Northern stock does not fit a perfect normal distribution, a logarithmic function has been applied for modeling the length data of this stock. The relative standardized length obtained using the base case model for the set of observations from the North and South Atlantic suggested that all the explanatory variables tested contributed significantly to explain part of the deviance and the results show a stable trend of the relative mean length over time and a light increase in the most recent period (**Figure 7**). Sensitivity analyzes tested have provided identical tends over time to the base case GLM model.

The distribution patterns of the blue shark vary depending on the life stage and the respective length of the individuals, so the variability may be attributed to the currents, thermal or other habitat conditions in the epipelagic layers, as well as to the spatial and seasonal segregation by sex, mating areas, pupping grounds and nursery areas (Litvinov 2006, Nakano and Stevens 2008, Carvalho *et al.* 2011, Mejuto and García-Cortés 2005). It is important to note that the present results are general trends based on the information available and that the distribution may vary depending on many factors such as very complex habitat factors including the available prey populations in a particular year or region.

The results suggest a highly extent of differentiation of its range. As described in previous studies with the broadest geographic ranges analyzed (i.e. Mejuto and García-Cortés 2005, Coelho *et al.* 2017, Druon *et al.* 2022) the largest individuals of both stocks seem to be mainly observed in the equatorial and tropical areas with warmer surface layers. Individuals of a wide range of lengths can be observed in intermediate-subtropical zones, while the relatively smaller individuals regularly appear in temperate zones of both hemispheres. However, this latitudinal-simplification should be qualified with a longitudinal vision, since the thermal conditions in the superficial layers between the Eastern and the Western Atlantic are very different due to their respective cold and warm surface currents and habitats.

A huge variability of all stages were observed in different habitat conditions confirming the widespread distribution of blue shark populations as described in the literature and also based on the abundant tagging-recapture data available to date.

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Table 1. Number of observations (N) and total number of individuals of *Prionace glauca* by sex (unknown: N_Unk, female: N_Female, and male: N_Male), mean length in FL cm (Mean) and standard deviation (Std. dev) for the period 1997-2021 obtained in the North and South Atlantic stocks.

	N	*N_Unk*	*N_Female*	*N_Male*	*Mean (FL cm)*	*Std. dev*
North stock	453504	113989	157793	181722	140.30	40.87
South stock	173167	122659	16783	33725	194.37	28.36

Table 2. Number of *Prionace glauca* individuals sampled during the period 1997-2021 in the North Atlantic stock. Most representative statistics are presented for each year (N: number of sampled fish, FL Max: maximum length (FL cm), FL Min: minimum length (FL cm), FL Mean: arithmetic mean of the length (FL cm), Std. dev: standard deviation and CV: coefficient of variation).

Year	*N*	*FL Max*	*FL Min*	*FL Mean*	*Std. dev*	*CV*
1997	53169	297	62	112.95	31.15	27.58
1998	25262	292	67	133.74	41.71	31.19
1999	38710	297	62	134.07	36.40	27.15
2000	16302	297	57	143.63	41.99	29.24
2001	22392	292	57	139.75	42.22	30.21
2002	15107	302	67	149.41	39.03	26.12
2003	12562	297	52	151.09	39.57	26.19
2004	15012	307	67	144.30	42.58	29.51
2005	10757	292	62	139.89	37.36	26.71
2006	12561	312	62	149.26	44.55	29.85
2007	11557	287	52	133.98	37.15	27.72
2008	7572	292	67	142.09	44.56	31.36
2009	7621	297	52	158.94	46.93	29.53
2010	11594	292	57	158.95	47.39	29.81
2011	14057	312	67	147.29	45.74	31.05
2012	14918	292	72	145.64	40.67	27.93
2013	17583	292	57	136.46	38.14	27.95
2014	28307	292	62	135.02	39.70	29.40
2015	23016	302	52	139.63	34.56	24.75
2016	20459	292	67	147.32	37.69	25.58
2017	18042	287	62	151.79	37.78	24.89
2018	10781	277	72	139.16	33.90	24.36
2019	8340	282	72	139.62	38.62	27.66
2020	15338	347	72	161.57	36.77	22.76
2021	22485	347	72	161.34	36.61	22.69
Total	**453504**	**347**	**52**	**140.30**	**40.87**	**29.13**

Table 3. Number of *Prionace glauca* individuals sampled during the period 1997-2021 in the South Atlantic stock. Most representative statistics are presented for each year (N: number of sampled fish, FL Max: maximum length (FL cm), FL Min: minimum length (FL cm), FL Mean: arithmetic mean of the length (FL cm), Std. dev: standard deviation and CV: coefficient of variation).

Year	*N*	*FL Max*	*FL Min*	*FL Mean*	*Std. dev*	*CV*
1997	8750	287	112	189.16	22.71	12.01
1998	7898	277	102	196.52	25.26	12.86
1999	7993	267	92	197.70	24.10	12.19
2000	6575	272	117	200.65	25.14	12.53
2001	8604	262	117	202.76	22.58	11.13
2002	16433	292	72	189.24	30.04	15.87
2003	8805	287	77	193.53	33.99	17.56
2004	5799	262	122	200.43	20.32	10.14
2005	8000	292	112	197.62	21.00	10.63
2006	13511	312	77	203.62	24.78	12.17
2007	13676	317	82	190.23	28.45	14.96
2008	8177	307	77	174.50	35.73	20.48
2009	10654	287	77	187.61	24.75	13.19
2010	9379	277	107	189.21	31.96	16.89
2011	4671	292	82	191.98	29.24	15.23
2012	5899	267	57	186.82	20.04	10.73
2013	3232	272	97	193.50	25.00	12.92
2014	2192	302	107	196.78	25.80	13.11
2015	2272	307	92	199.56	27.35	13.70
2016	12	282	202	248.67	26.05	10.48
2017	2558	252	92	186.17	17.65	9.48
2018	3778	297	107	206.83	24.13	11.66
2019	0	N/A	N/A	N/A	N/A	N/A
2020	4592	287	102	197.39	22.52	11.41
2021	9707	327	67	208.21	35.74	17.17
Total	**173167**	**327**	**57**	**194.37**	**28.36**	**14.59**

Table 4. Number of *Prionace glauca* individuals of sampled during the period 1997-2021 in the North Atlantic stock and most representative statistics, by quarter (N: number of sampled fish, FL Max: maximum length (FL cm), FL Min: minimum length (FL cm), FL Mean: arithmetic mean of the length (FL cm), Std. dev: standard deviation and CV: coefficient of variation).

Quarter	*N*	*FL Max*	*FL Min*	*FL Mean*	*Std. dev*	*CV*
1	139682	347	52	129.96	38.85	29.90
2	122159	347	52	138.56	39.53	28.53
3	94562	312	52	149.31	43.31	29.01
4	97101	302	52	148.57	39.14	26.34

Table 5. Number of *Prionace glauca* individuals sampled during the period 1997-2021 in the South Atlantic stock and most representative statistics, by quarter (N: number of sampled fish, FL Max: maximum length (FL cm), FL Min: minimum length (FL cm), FL Mean: arithmetic mean of the length (FL cm), Std. dev: standard deviation and CV: coefficient of variation).

Quarter	*N*	*FL Max*	*FL Min*	*FL Mean*	*Std. dev*	*CV*
1	45151	317	77	190.31	25.80	13.55
2	44599	307	72	196.17	25.38	12.94
3	38849	327	67	196.15	29.70	15.14
4	44568	322	57	195.13	31.85	16.32

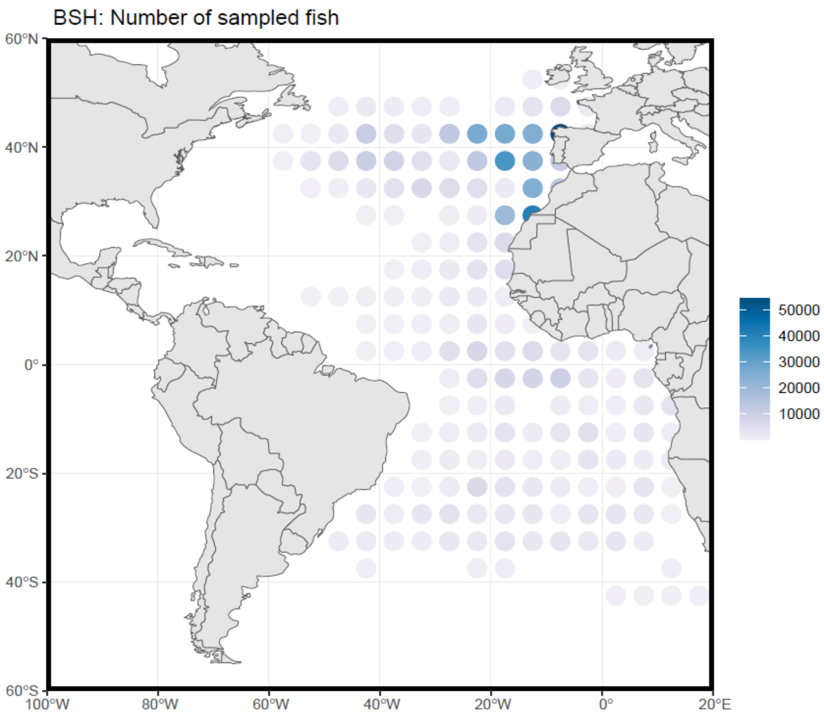


Figure 1. Spatial distribution of the total number of *Prionace glauca* length-sampled. The color represents the number of fish by 5ºx5º grid.

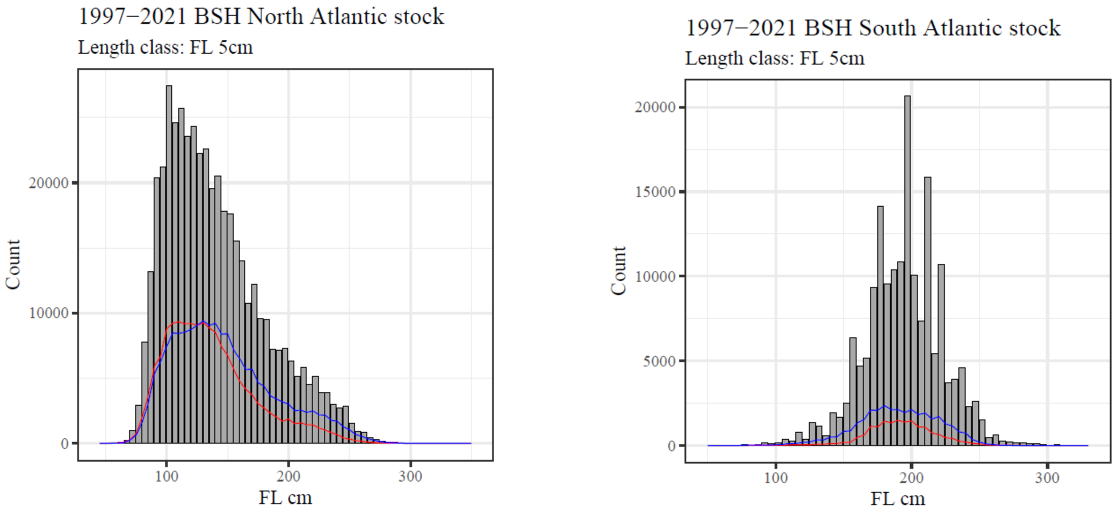


Figure 2. Length distribution (FL cm) of *Prionace glauca* sex-combined and by sex, for each Atlantic stock (red line: females, blue line: males) for the period 1997-2021.

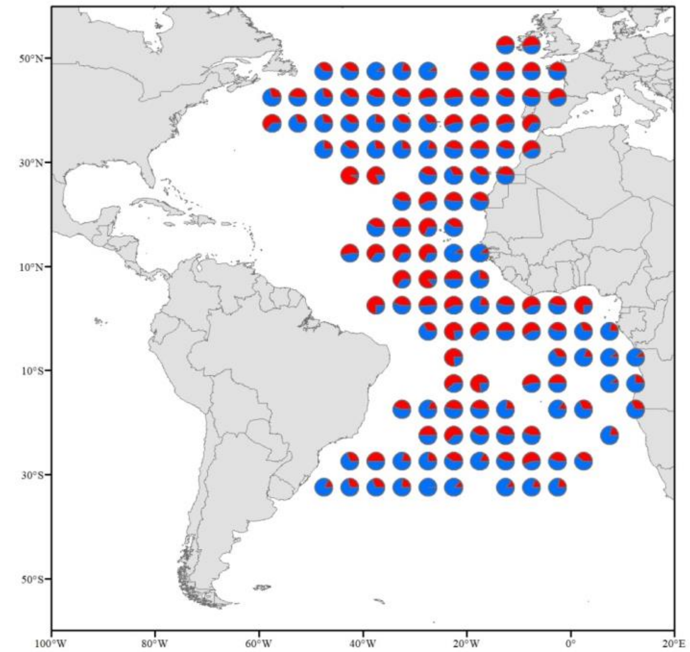


Figure 3. Sex-ratio of *Prionace glauca* per 5ºx5º square in the Atlantic Ocean, years combined (red=female, blue=male).

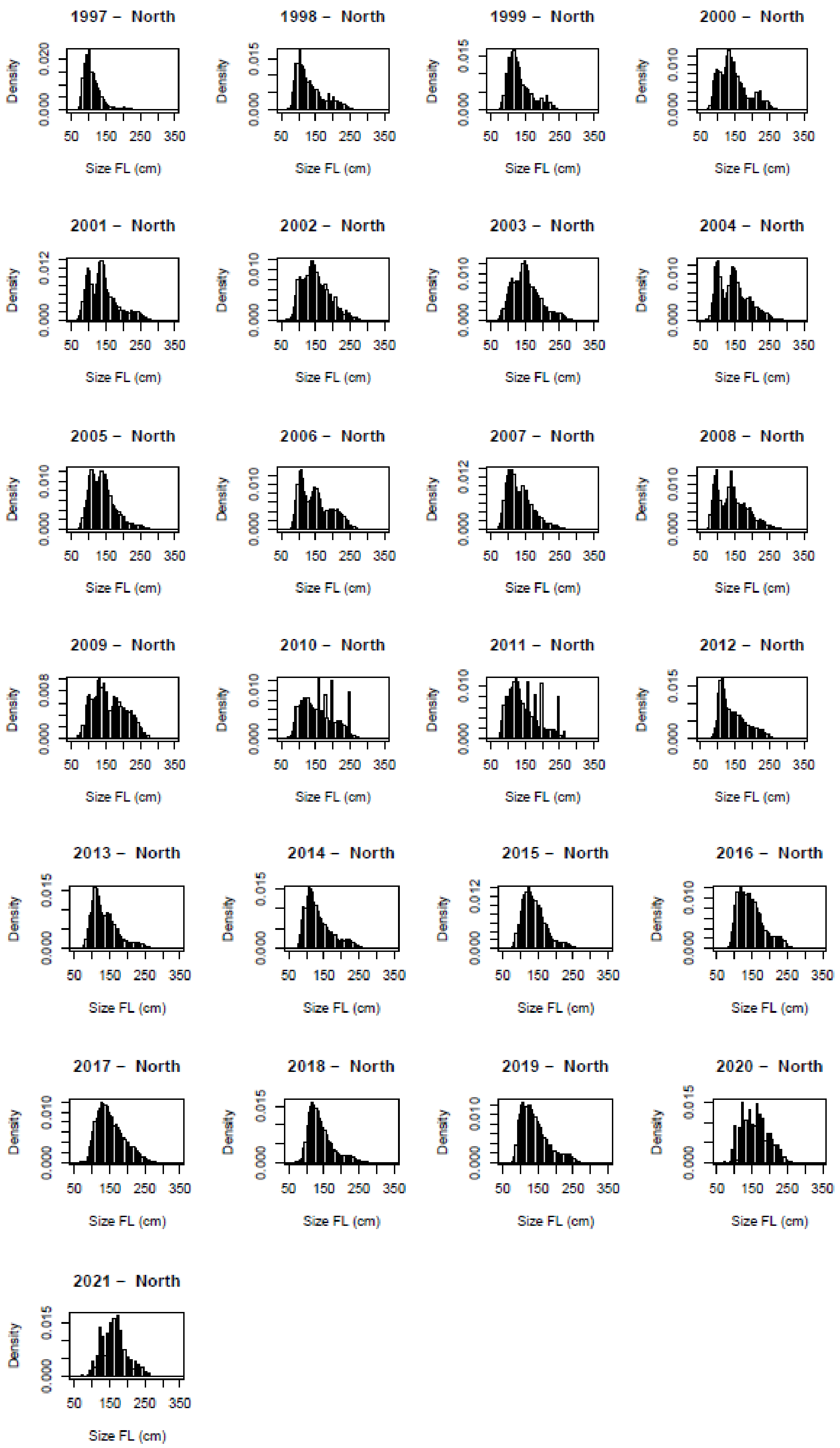


Figure 4. Total length distribution (FL cm) of *Prionace glauca* by year for the North Atlantic stock.

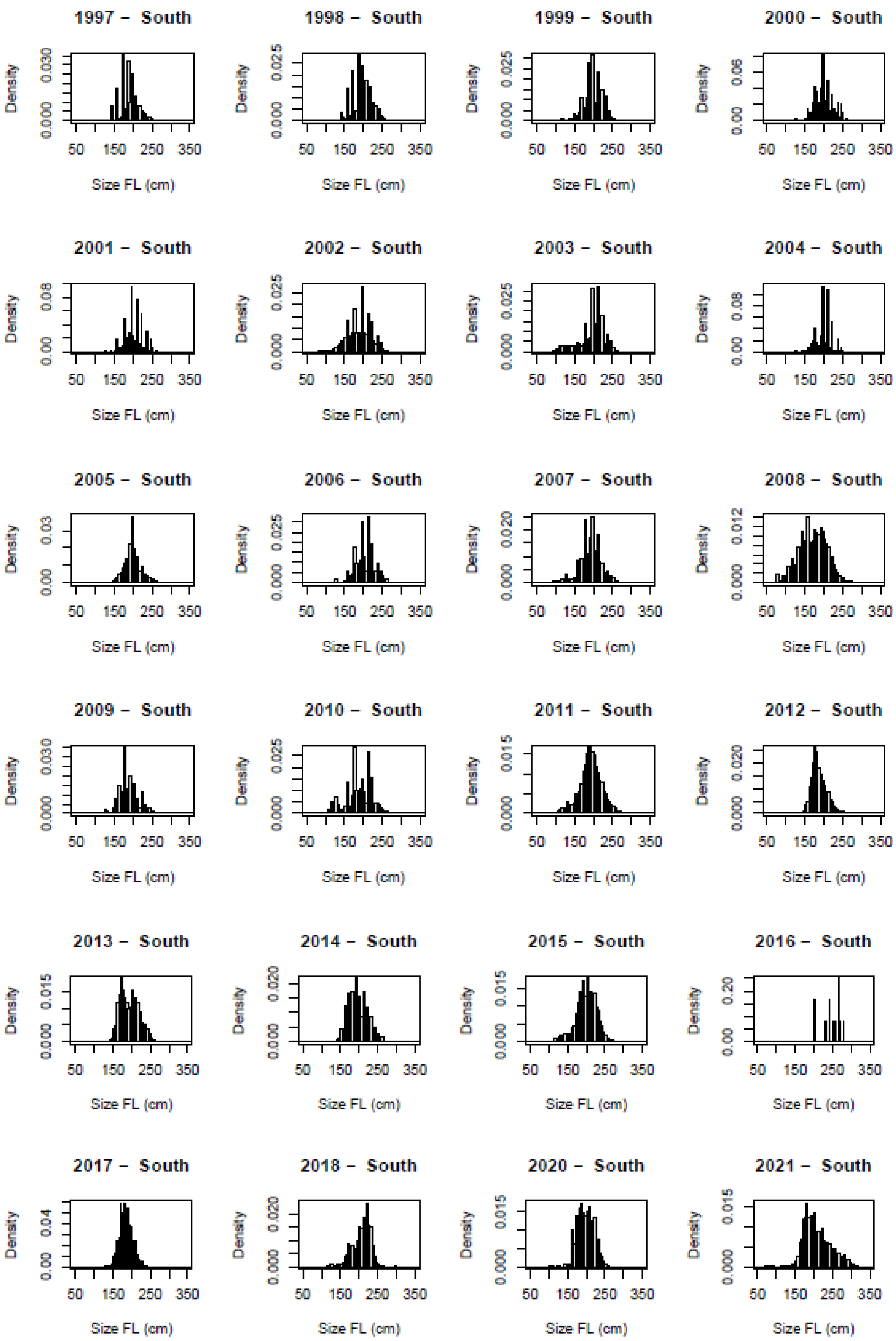
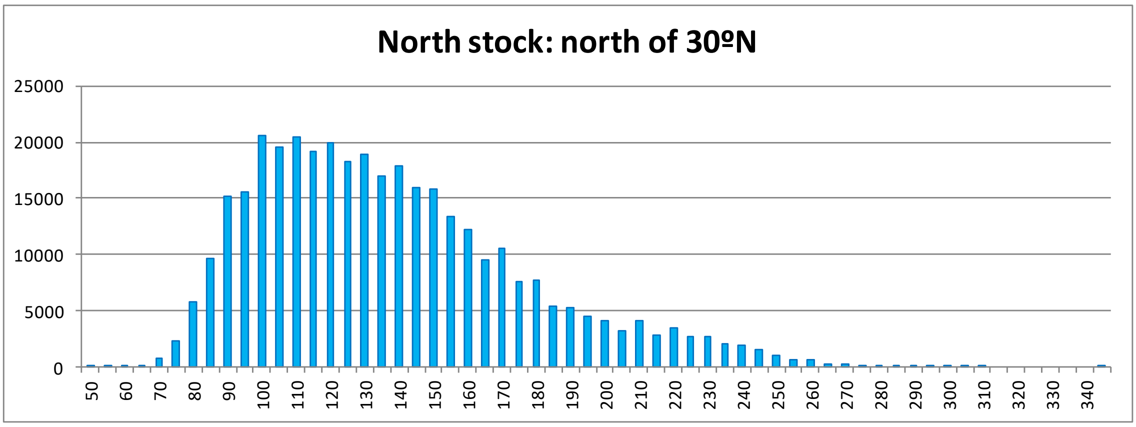


Figure 5. Total length distribution (FL cm) of *Prionace glauca* by year for South Atlantic stock.



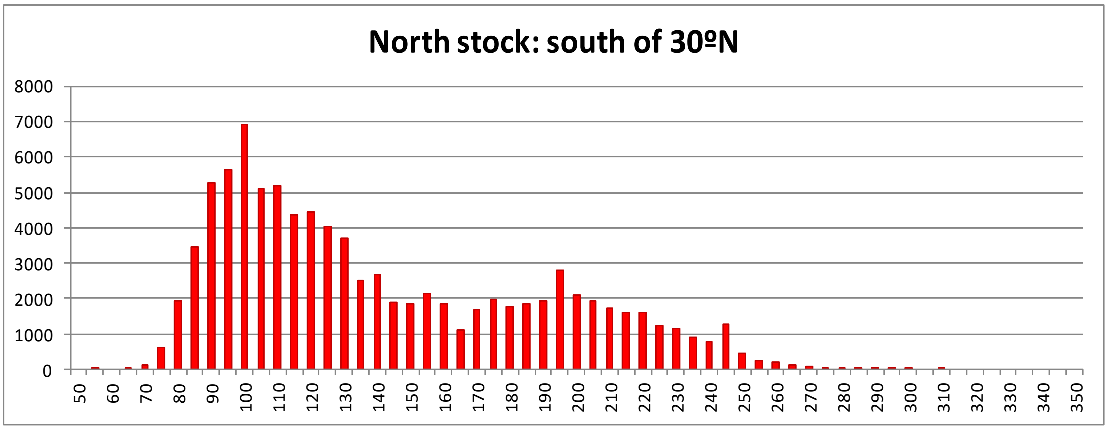


Figure 6. Total length distribution (FL cm) of the Northern stock of blue shark *Prionace glauca*, split for North and South of 30ºN latitude.

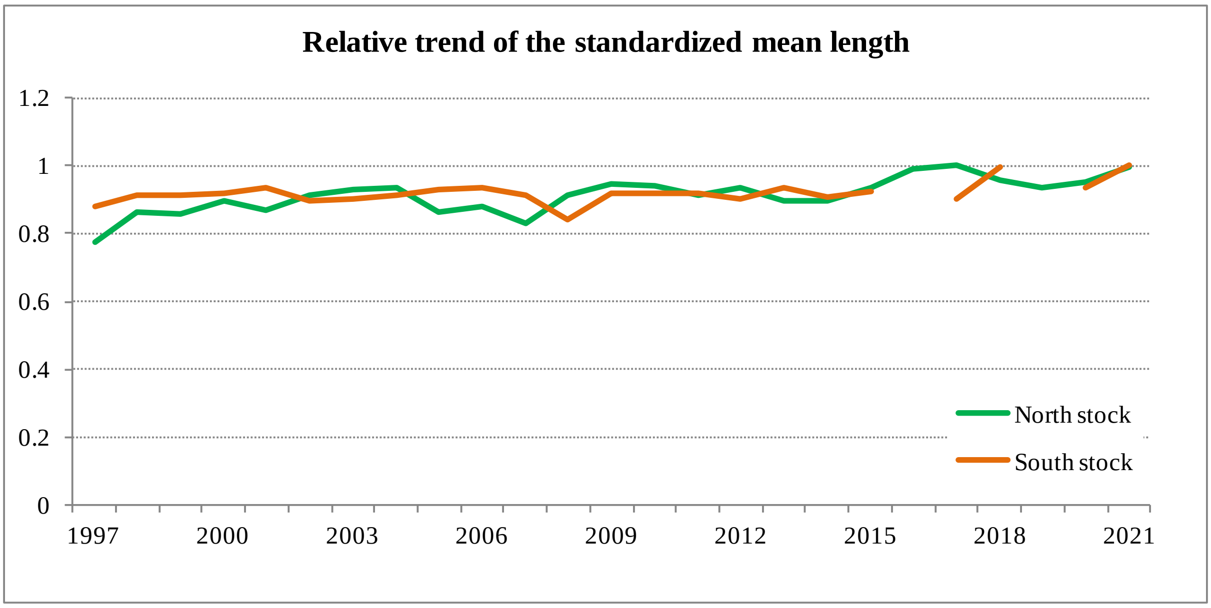


Figure 7. Relative standardized length of *Prionace glauca* by year, for the North and South Atlantic stocks.